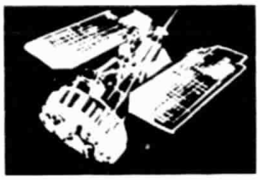
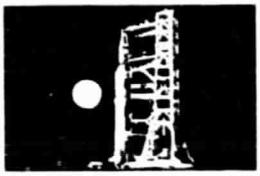
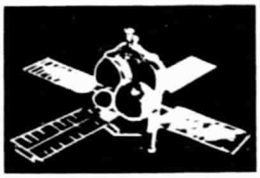
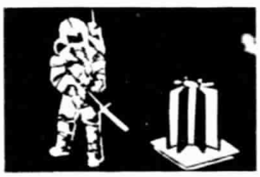
SPACE
DIVISION






NASA CR-121223 - Vol II
GE Document No. GESP-7103
December 1973

FINAL REPORT
MINI-BRAYTON HEAT SOURCE ASSEMBLY
DESIGN STUDY

VOLUME II
TITAN IIIC MISSION

GENERAL ELECTRIC

NASA CR-121223
GE Document No. GESP-7103
December 1973

FINAL REPORT

MINI-BRAYTON HEAT SOURCE ASSEMBLY

DESIGN STUDY

Performed Under

Contract NAS 3-16810

FOR

NATIONAL AERONAUTICS & SPACE ADMINISTRATION
LEWIS RESEARCH CENTER
21000 BROOK PARK ROAD
CLEVELAND, OHIO 44135

VOLUME II

TITAN IIIC MISSION

ENERGY SYSTEM PROGRAMS
SPACE DIVISION
Valley Forge Space Center
P. O. Box 8661, Philadelphia, Penna. 19101

GENERAL ELECTRIC

TABLE OF CONTENTS

PRECEDING PAGE BLANK NOT FILMED

LIST OF ILLUSTRATIONS

LIST OF TABLES

PREFACE

This final report for a Mini-Brayton Heat Source Assembly is presented in two volumes. Volume 1 contains the study results for modular design concepts predicated on a space shuttle Mission. Volume 11 contains the study results for a minimum weight Heat Source Assembly designed for a Titan 111 C, synchronous orbit mission.

SECTION 1

INTRODUCTION

SECTION 1

INTRODUCTION

This report summarizes the results of the Mini-Brayton Heat Source Assembly design study. The study has been performed for the NASA Lewis Research Center under contract NAS 3-16810.

1.1 OBJECTIVES

The objective of this study was to develop conceptual design definitions of a Heat Source Assembly (HSA) for use in nominal 500 watt electrical (W(e)), 1200 W (e) and 2000 W (e) Mini-Brayton isotope power systems. The HSA is an independent package which maintains thermal and nuclear control of an isotope fueled Heat Source (HSA) and transfers the thermal energy to a Brayton Rotating Unit (BRU)-Turbine-Alternator-Compressor power conversion unit.

1.2 SCOPE

The program was divided into the following four major tasks.

I	Safety
II	Conceptual Designs
III	Design Definitions
IV	Minimum Weight Conceptual Design

Volume I of this final report contains the results of Tasks I, II and III. Volume II is devoted to the Minimum Weight concept developed during Task IV. The safety study, Task I, focused on the general safety problems associated with an isotope fueled Mini-Brayton system. The purpose was to develop safety design requirements and guidelines, consistent with a space shuttle launch, which must be factored into the HSA designs. The manned space shuttle was selected as the reference mission since it imposes the most stringent safety requirement and represents a likely launch vehicle for future missions. Emphasis was placed on thermal control, radiation protection and blast and fragmentation protection. Space shuttle integration considerations, hazards, and potential accidents were identified. A preliminary function flow analysis for the baseline shuttle mission

encompassing the time frame between fabrication and recovery of the Heat Source was generated to facilitate this. The output of this investigation was a set of safety design requirements and guidelines to ensure personnel safety through all mission phases; to minimize the potential for accidents; and to preclude release of nuclear fuel to the biosphere in the event of catastrophic accidents or failures.

The purpose of the Conceptual Design Study, Task II, was to develop candidate HSA design concepts for a Space Shuttle mission that satisfy both design and safety requirements. Concepts for each of the HSA functional components (except for the Heat Source) were studied and the most promising ones integrated into overall HSA concepts. The output was a number of different HSA concepts with an evaluation of advantages and disadvantages of each. The Design Definition, Task III, encompassed more detailed definition of the three most attractive conceptual designs for the Space Shuttle mission. The task included selection of candidate materials, fabrication and assembly studies, thermal and hydraulic performance analysis and structural sizing, and design layouts. Also included in this effort was the definition of Ground Handling and Orbit Handling tools to ensure HSA design compatibility with nuclear handling requirements. Task IV, Minimum Weight Conceptual Design, represented a modification to the original contract and was directed toward a nominal 500W (e) system for a Titan III C launch to syncronous orbit. Some of the basic ground rules and design requirements that apply to the Space Shuttle mission (Tasks I, II and III) are different and consequently had a major impact on the design of the HSA.

1.3 MINI-BRAYTON SYSTEM DESCRIPTION

The Mini-Brayton power system is a closed gas loop system consisting fundamentally of five major subsystems: a heat exchanger which accepts the energy from the heat source (this assembly is the HSA), a Brayton rotating unit (BRU) which converts this heat energy into electrical power, a heat rejection system which dissipates the waste heat, a recuperator which enhances system efficiency, and an electrical control system.

The Brayton power conversion system is depicted in Figure 1-1. Energy is added by the heat source to the working fluid in the HSHX, shown as Points 1 to 2. The gas leaves the HSHX and is expanded in the turbine, Points 2 to 3. At Point 4, the gas entering the recuperator from the turbine, preheats the gas entering the HSHX and consequently, is cooled before entering the radiator.

Heat is rejected from the system in a radiator, Points 5 to 6. After exiting from the radiator the gas is isentropically compressed, Points 7 to 8, and is returned to the recuperator at Point 9.

Three nominal electrical output power levels--500 W(e), 1200 W(e) and 2000 W(e) were considered; the system configuration for each of the three power levels is depicted, in Figure 1-2. For output power levels greater than 500 W(e), two or three 2400 W(e) HSA's are manifolded in parallel and interfaced with a single power conversion system (defined on Figure 1-1).

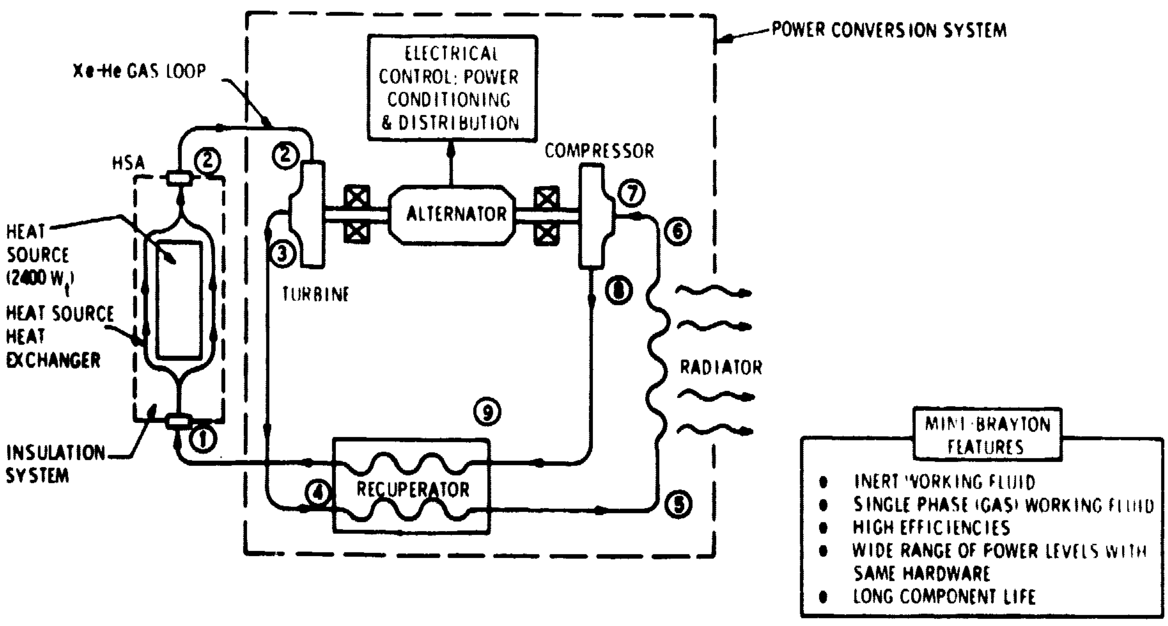


Figure 1-1. Typical Isotope-Brayton System (500 W_e)

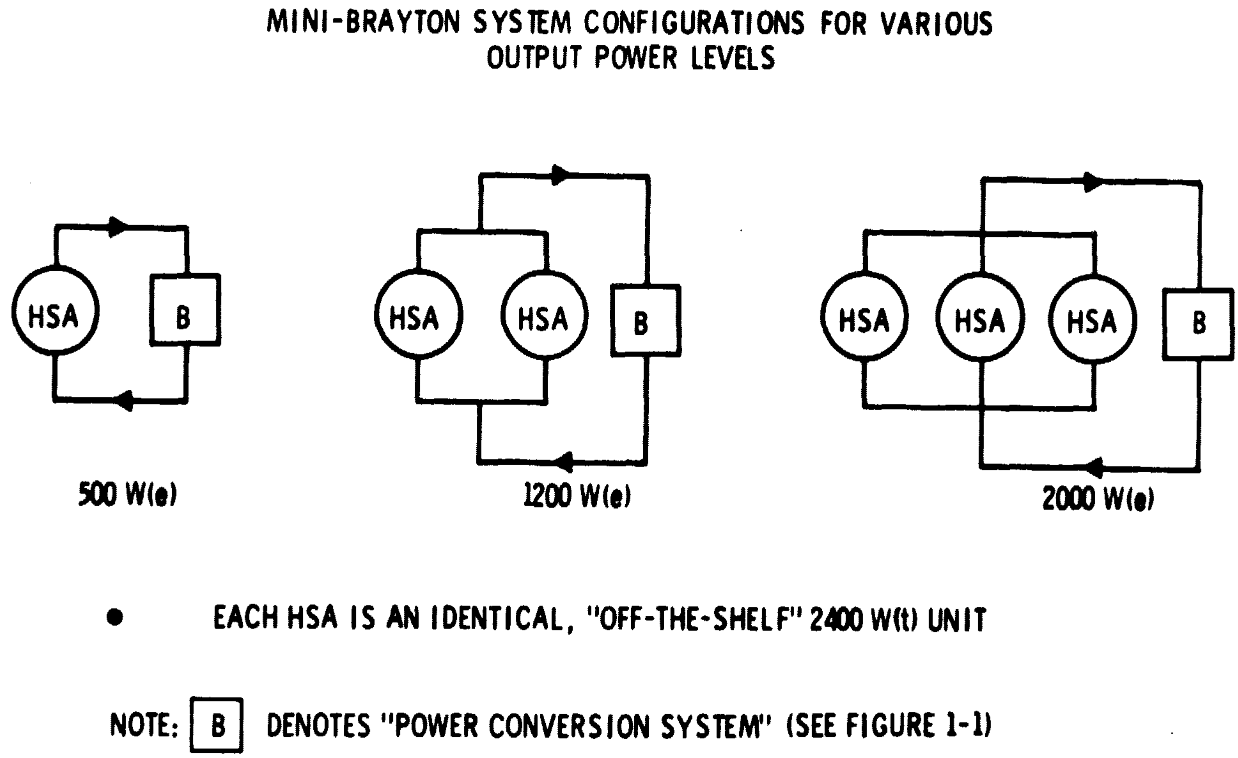


Figure 1-2. Mini-Brayton System Configuration for Various Output Power Levels

The Brayton power cycle has several outstanding characteristics which makes it very attractive for space applications. First, the use of an inert gaseous working fluid allows the cycle to operate over a wide temperature range which provides high Carnot efficiencies; by employing a recuperator, high system efficiencies can be realized. Secondly, the system is adaptable for efficient operation over a wide range of power levels which can be controlled by changing the system operating pressure while the turbomachinery size remains fixed. Thirdly, a gaseous working fluid allows the use of simple, self-acting gas bearings, ensuring long component life.

An artist conception of an integrated Mini-Brayton Power Module mounted on a typical spacecraft is shown in Figure 1-3.

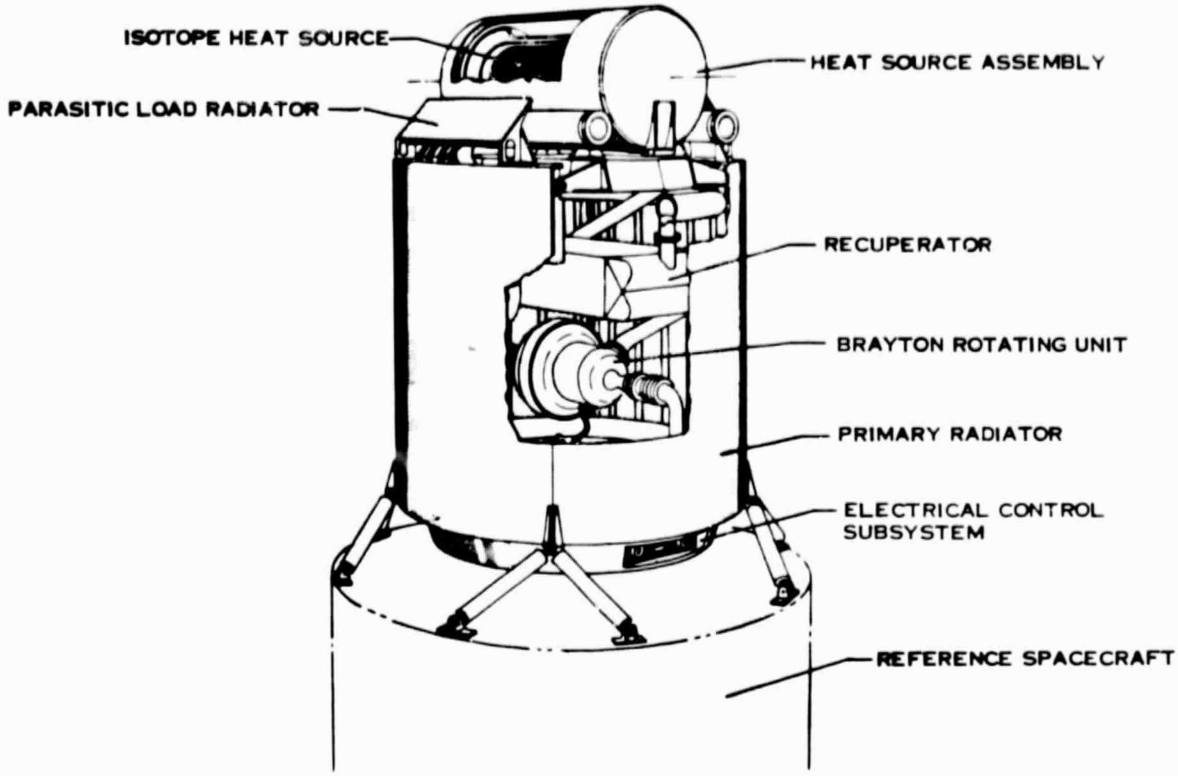


Figure 1-3. Mini-Brayton System Power Conversion Module (Artist Conception)

1.4 HSA DEFINITION AND COMPONENTS

The Heat Source Assembly generates the thermal energy required for operation of the Mini-Brayton System and transfers this energy via a Heat Exchanger fluid loop to the Power Conversion System. The subsystems and respective components which collectively comprise the HSA are listed in Table 1-1.

The Heat Soruce is fueled with 2400 watts (thermal) of $^{238}PuO_2$ ceramic fuel of 82 percent theoretical density. The design provides positive safety margins for any re-entry up to 11,000 m/sec (36,000 ft/sec) and for all credible accident modes. Since the Heat Source will be flight qualified for the LES 8/9 mission, no additional design or test effort

will be required for the Mini-Brayton program. The Heat Source is described in detail in Section 4 of Volume I.

The Heat Source Heat Exchanger transfers heat from the Heat Source to the Power Conversion System by means of a Heat Exchanger and associated headers and manifolding.

The Auxiliary Cooling Subsystem provides required cooling of the Heat Source and refractory HSA materials during non-operational periods on the launch pad. Coolant is provided at the launch complex.

The Emergency Cooling Subsystem is a passive system that is automatically activated in emergency situations that could result in an over-temperature condition of the Heat Source. Such emergencies can be precipitated by unplanned delays in orbit achievement prior to starting up the power system; failure of the Power Conversion System (e. g. , loss of radiator integrity, BRU failure, leaks in the gas loop, etc.); unplanned shuttle landing in remote areas where auxiliary coolant is unavailable, etc. The ECS is capable of operating during all mission phases including prelaunch. It is unlikely, however, that the ECS would ever activate during the prelaunch phase since auxiliary cooling is provided and the Heat Soruce is under positive control.

The Inert Gas System (IGS) is used if required during Mini-Brayton prelaunch operational periods at power to protect HSA refractory materials in oxidizing environments. The subsystem utilizes the manifolding and cooling channels of the Auxiliary Cooling System for the concept developed for the Space Shuttle mission, and provides an inert cover gas of the appropriate purity. In essence the IGS is identical to the ACS if the same coolant is used for auxiliary cooling, except that flow rates may be lower (controlled by appropriate valving).

The Heat Source Insulation Subsystem consists of multifoil insulation blankets which surround the HSA structure and minimizes the heat loss from the system. Penetrations

through the insulation are provided for the primary cooling system (and Auxiliary Cooling Subsystem manifolds for the Space Shuttle mission).

Table 1-1. Heat Source Assembly Subsystems and Components

Subsystem or Component	Symbol	Function	Major Components
Heat Source	HS	Source of Thermal Energy for Power Conversion System (2400 W (t))	• PuO_2 Fuel • Re-entry Protection Systems • Emissivity Sleeve
Heat Source Heat Exchanger	HSHX	Transfers heat from the HS to the Power Conversion System during Normal Operation	• Heat Exchanger • Headers • Manifolds
Auxiliary Cooling Subsystem	ACS	Cools HS during Non-Operational Periods on Launch Pad	• Manifolds • Coolant
Emergency Cooling Subsystem	ECS	Cooling Doors and Associated Devices which Automatically Open the Doors in Emergency Situations (for space shuttle mission); melting insulation for Titan III C mission	• Insulated Doors • Hinges and Latches • Emergency Cooling Device (ECD) • Melting Insulating
Inert Gas Subsystem	IGS	Provides Inert Gas Environment (Cover Gas) To Protect HSA Internals in Oxidizing Environments at Power	• Inert Gas • Valving
Heat Source Insulation Subsystem	---	Limits Heat Loss from HS during Operation	• Multifoil Insulation

SECTION 2

SUMMARY

SECTION 2

SUMMARY

The major conclusions of Task IV of the Heat Source Assembly study which addressed a minimum weight HSA design for a Titan III C mission are summarized in this section.

The new ground rule for the Titan III C mission, that eliminates the Space Shuttle mission requirement to recover the Heat Source in orbit, has a major impact on the HSA design. It relaxes the requirement for providing an access door for in-orbit removal of the Heat Source and results in a substantial weight reduction. It permits the Heat Source End Enclosure supports and HSA Support Housing to be located in a low temperature region external to the insulation enclosure. Titanium and Beryllium alloys respectively, are employed for these support elements rather than the much heavier refractory alloy required in the Space Shuttle HSA design (Volume I).

Elimination of the emergency cooling doors which served as access doors in the Shuttle HSA design, requires design of a different emergency cooling subsystem to preclude Heat Source over-temperature in event of Mini-Brayton system failures. An insulation blanket which melts in the range 2000° F to 2700° F and permits thermal energy to be dissipated to space, was selected to provide this function. Nickel foil coated with Zirconia, or gold foil separated with glass fiber layers will melt sufficiently quickly after onset of an emergency, to prevent the isotope Heat Source from reaching unsafe temperatures.

The HSA design selected for the Titan III C mission is given in Figure 2-1. An exploded view is shown in Figure 2-2. It features the same Columbium Alloy HSHX selected for the Space Shuttle mission except that wall gages were reduced (sized for a 500 Watt Mini-Brayton system) and the HSHX support structure greatly simplified. The Heat Source End Enclosure Supports (spiders) are titanium and are essentially identical to the MHW-RTG design. The HSA Support Housing, located external to the insulation blanket, is

fabricated from Beryllium and provides the mechanical interface attachments with the system hardware. These design features have resulted in weight reduction from 77.7 kg (171 lbs.) for the space shuttle design to 38.1 kg (84 lbs.) for the Titan III C design. This minimum weight HSA can be designed for a HSHX pressure level of 79N/Cm^2 (115 psi) for incorporation in a 2 to 3 KW power output Mini-Brayton system for a weight penalty of 1. kg (2.3 lbs). The minimum weight design incorporates all of the safety design characteristics of the shuttle design descussed in Sections 2.1.2 and 5 of Volume I.

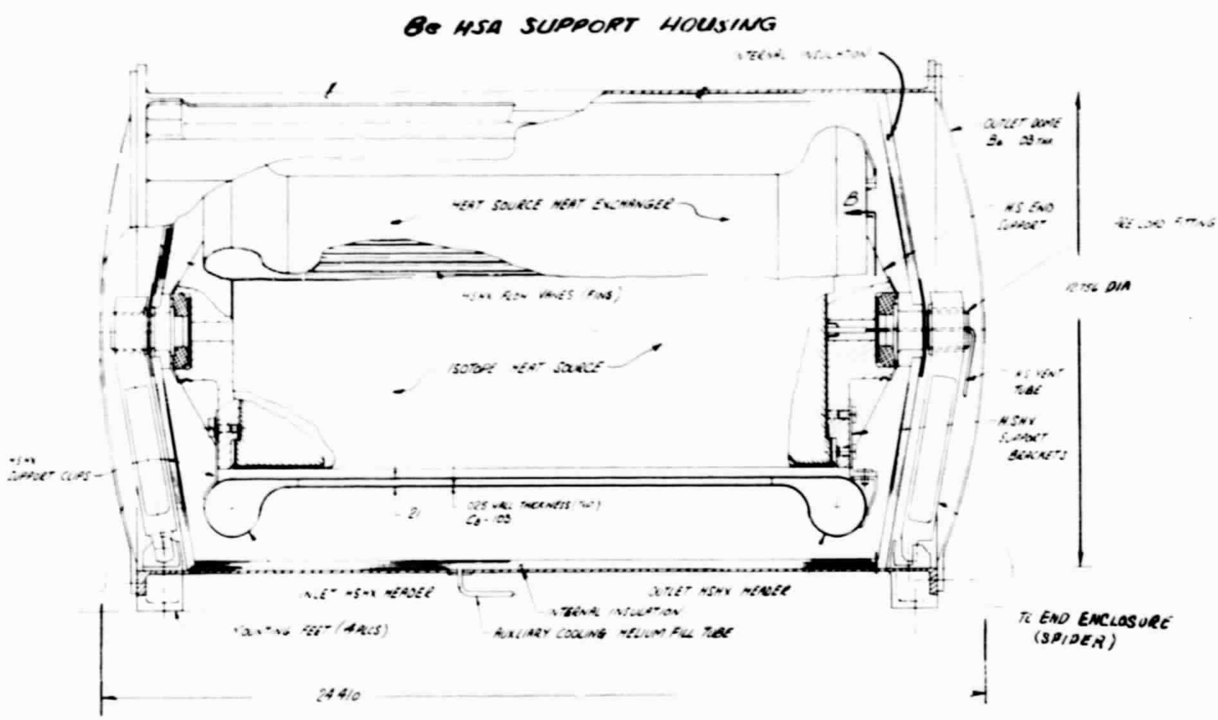


Figure 2-1. Reference Baseline HSA

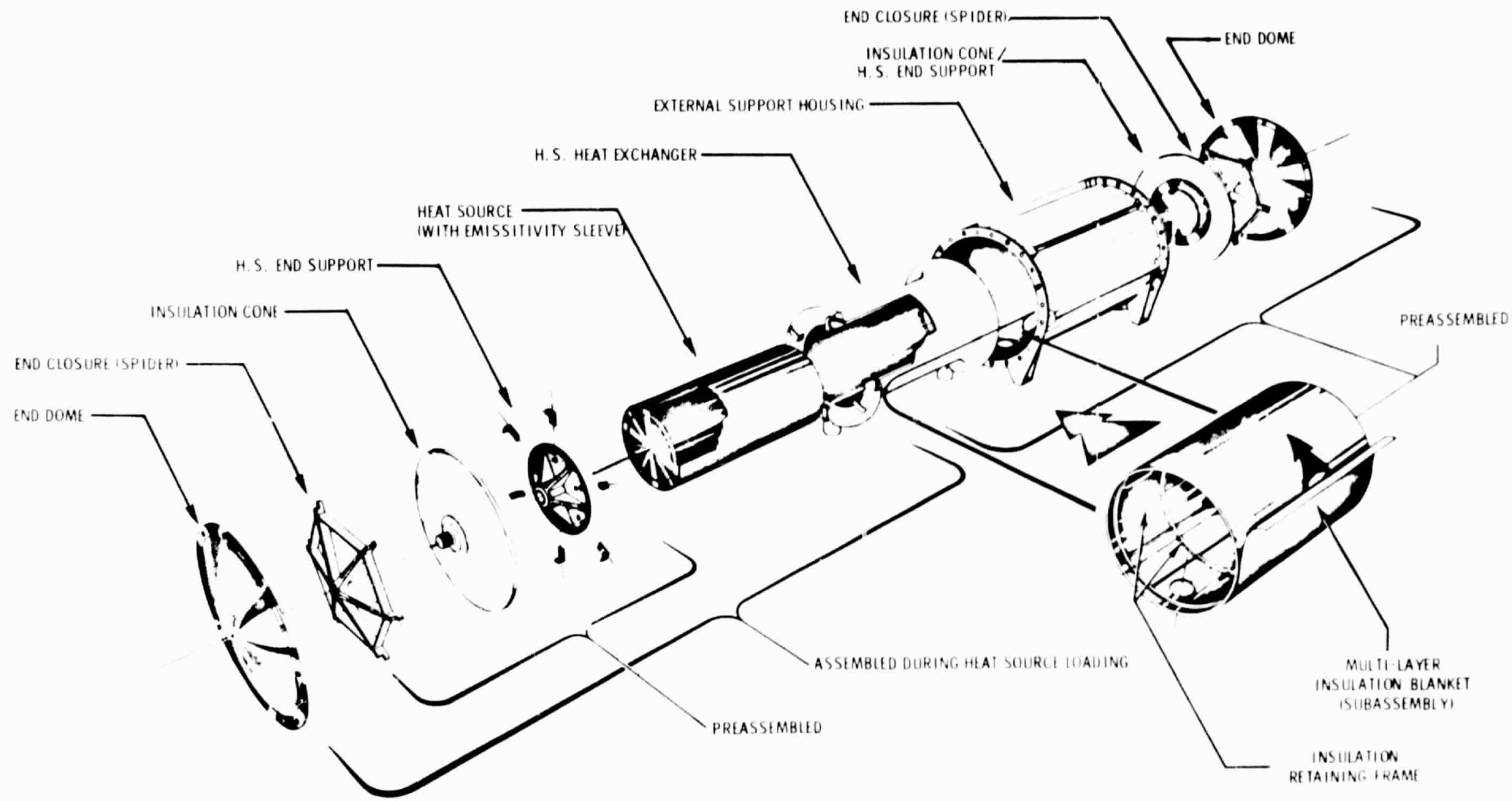


Figure 2-2. Reference Baseline Heat Source Assembly - Exploded View

SECTION 3

DESIGN REQUIREMENTS

SECTION 3

DESIGN REQUIREMENTS

3.1 GUIDELINES

The Guidelines approved for the Titan III C mission minimum weight design are as follows:

1. The Heat Source Assembly shall be designed to result in a minimum weight HSA for a HSHX working fluid pressure of $41 N/cm^2$ (60 psi). *This results in a threshold below which wall gauges cannot be reduced because of fabrication limitations.*

2. The target weight for the HSA is 40 Kg (88 lbs) or less.

3. The Emergency Cooling Subsystem may utilize an electrical signal for activation. Pyrotechnics devices may also be utilized providing they do not introduce a radiological hazard and provided they exhibit high reliability of operation after 5 years in a space environment.

4. Auxiliary Cooling should have the capability of limiting exposed surfaces of the HSA to a temperature not exceeding 466.5^oK (380^oF) on the launch pad. *This is to preclude auto-ignition of spacecraft or booster hypergolic propellant.*

5. The design of the HSHX and any other high temperature component within the insulation enclosure will be based on utilizing either of the refractory alloys, Cb-103 or Cb-1Zr.

6. HSHX structural sizing shall be based on 1% creep stress limits in the longitudinal direction and 2% in the radial direction. These are the same criteria used in the space shuttle mission design.

7. The working fluid flow rate through a HSA shall be 0.057 Kg/sec. (0.125 lb/sec).

8. The HSHX shall be designed for an inlet temperature of 989^oF (1320^oF) and outlet temperature of 1153^oF (1615^oF). *The use of refractory alloys will permit higher inlet and outlet temperatures than this.*

9. The MHW Pu-238 Heat Source may be modified to eliminate the emissivity sleeve (girdle) if it is determined that either it is not required for the HSA design or that it compromises a direct Heat Source Cooling approach (working fluids flow directly over the Heat Source). This modified Heat Source can be incorporated only if it does not compromise radiological safety.

10. The MHW Pu-238 Heat Source Iridium Clad may be modified to include a mounting bracket(s) or frame(s) to support the Heat Exchanger provided this does not comprise radiological safety.

11. There shall be no requirement to remove nor recover the Heat Source in orbit.

12. There shall be no requirement to load the Heat Source into the assembly on the pad. This implies that the Heat Source can be loaded at anytime prior to on pad operations, and that the HSA may be sealed.

Guideline 1 was based on an analysis which indicated that for working fluid pressure levels below $41 N/cm^2$ (60 psi), fabrication limits for minimum refractory wall gauges would prevail.

Guideline 3, allowing the use of an electrical signal to activate the emergency cooling system, was not employed in the design.

Guideline 7 and 8 above are identical to the Space Shuttle HSA design requirements for a Mini-Brayton system with a single HSA. The flexibility to accommodate minor modifications to the MHW Heat Source (Guidelines 9 and 10) were not employed in the minimum weight design.

As indicated in Section 2, the lack of any requirement to remove the Heat Source in orbit (Guideline 11) has a major impact on the design.

3.2 SAFETY CRITERIA

The safety design criteria relating to explosion, re-entry and impact environments, specified for the MHW Heat Source, which are given in Section 5.2 of Volume I, apply to the Titan III C mission HSA design. Additional safety requirements which apply to the temperature response of the Heat Source in the HSA configuration are as follows:

1. During an orbit operation the Heat Source external surface (girdle) temperature shall not exceed 1373°K (2012°F). This is based on the MHW Specification for the Heat Source. As a goal the HSA will be designed for a girdle temperature of less than 1283°K (1850°F).

2. During steady state condition after onset of an emergency situation resulting in loss of cooling, the Heat Source external surface temperature (girdle) shall not exceed 1490°K (2223°F). This temperature is based on the MHW Specification which prescribes that the maximum Iridium Post Impact Containment Shell (PICS) temperature for any extended period shall not exceed 1773°K (2732°F). (See Figure 4-1 of Volume I for definition of PICS.)

3. During the transient condition after onset of an emergency loss of cooling situation, the Heat Source PICS shall not exceed 2372°K (3810°F). This is based on the MHW Requirement that sets the maximum permissible PICS temperature for short periods of time (~ 15 minutes) at 200°F less than the iridium/carbon eutectic temperature of 2483°K (4010°F). This MHW requirement is presently being re-evaluated to determine if the maximum permissible PICS temperature should be set at a lower temperature to provide a safety margin for the unlikely event that a Mini-Brayton system failure is followed immediately by a re-entry.

SECTION 4

MINIMUM WEIGHT HSA CONCEPTS

SECTION 4

MINIMUM WEIGHT HSA CONCEPTS

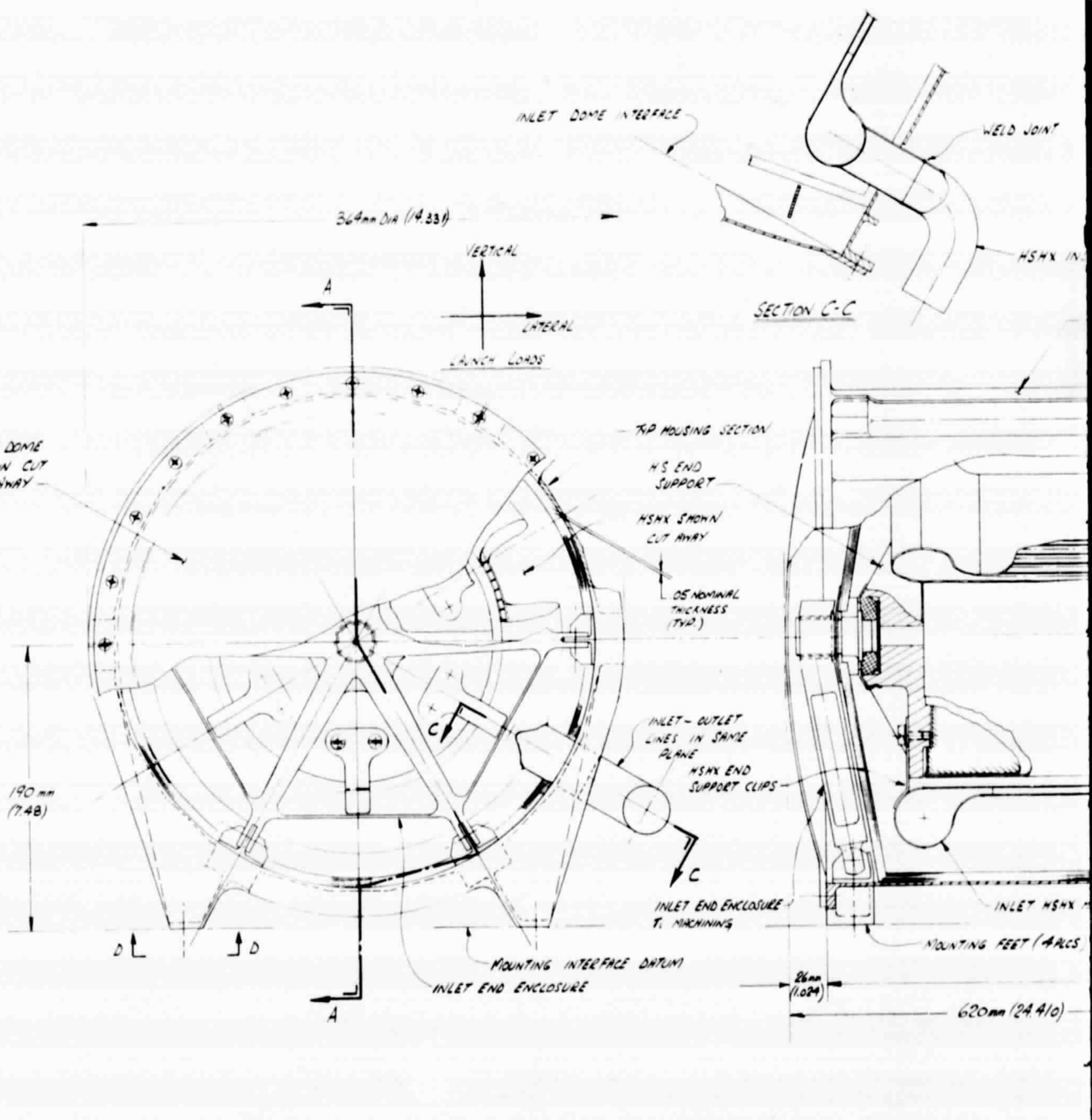
In developing minimum weight designs, two avenues of approach were pursued. One approach was to use the shuttle mission HSA design (Volume I - Figure 11-2) as a point of departure for effecting weight reductions by eliminating the emergency cooling doors and by utilizing titanium Heat Source supports (spiders) and a beryllium HSA support housing. The second approach was to develop entirely new concepts without any limitations other than adhering to the guidelines discussed in Section 3. As an example, a sealed HSA design in which the Mini-Brayton Xe-He working fluid flows directly over the Heat Source, appeared to have merit and was defined to sufficient depth to permit a trade-off evaluation. Similarly three other "new" HSA concepts were developed and evaluated.

4.1 REFERENCE BASELINE HEAT SOURCE ASSEMBLY DESIGN

Figure 4-1 shows the basic design features of the preferred design - the "Reference Baseline HSA". This configuration evolved from the Plate Fin HSA design developed for the space shuttle mission. The Heat Source Heat Exchanger is supported off the Heat Source by a spring cradle support on one end and an "L" shaped bracket on the opposite end, as shown in Figure 4-2. These iridium support brackets are attached to the graphite heat source end support pads. A shear pin on the "L" bracket permits radial growth of HSHX relative to the heat source. The spring cradle support permits longitudinal expansion relative to the heat source. An alternate support scheme is shown in Figure 4-3. An iridium pin attached to one end of the heat source engages a slotted columbium alloy "L" bracket welded to the HSHX, when the HSHX is installed, while on the other end a slotted iridium bracket engages a columbium alloy pin attached to the HSHX. This support also permits both longitudinal and radial growth of the HSHX relative to the Heat Source.

The Heat Source is supported by titanium end enclosures ("spiders") which engage the cylindrical beryllium support housing. The spiders are essentially identical to the MHW-RTG design and are preloaded at installation of the heat source. The graphite heat source end supports ("pads") and insulated preload fittings are also essentially identical to the MHW-RTG

FOLDOUT FRAME



FOLDOUT FRAME

2

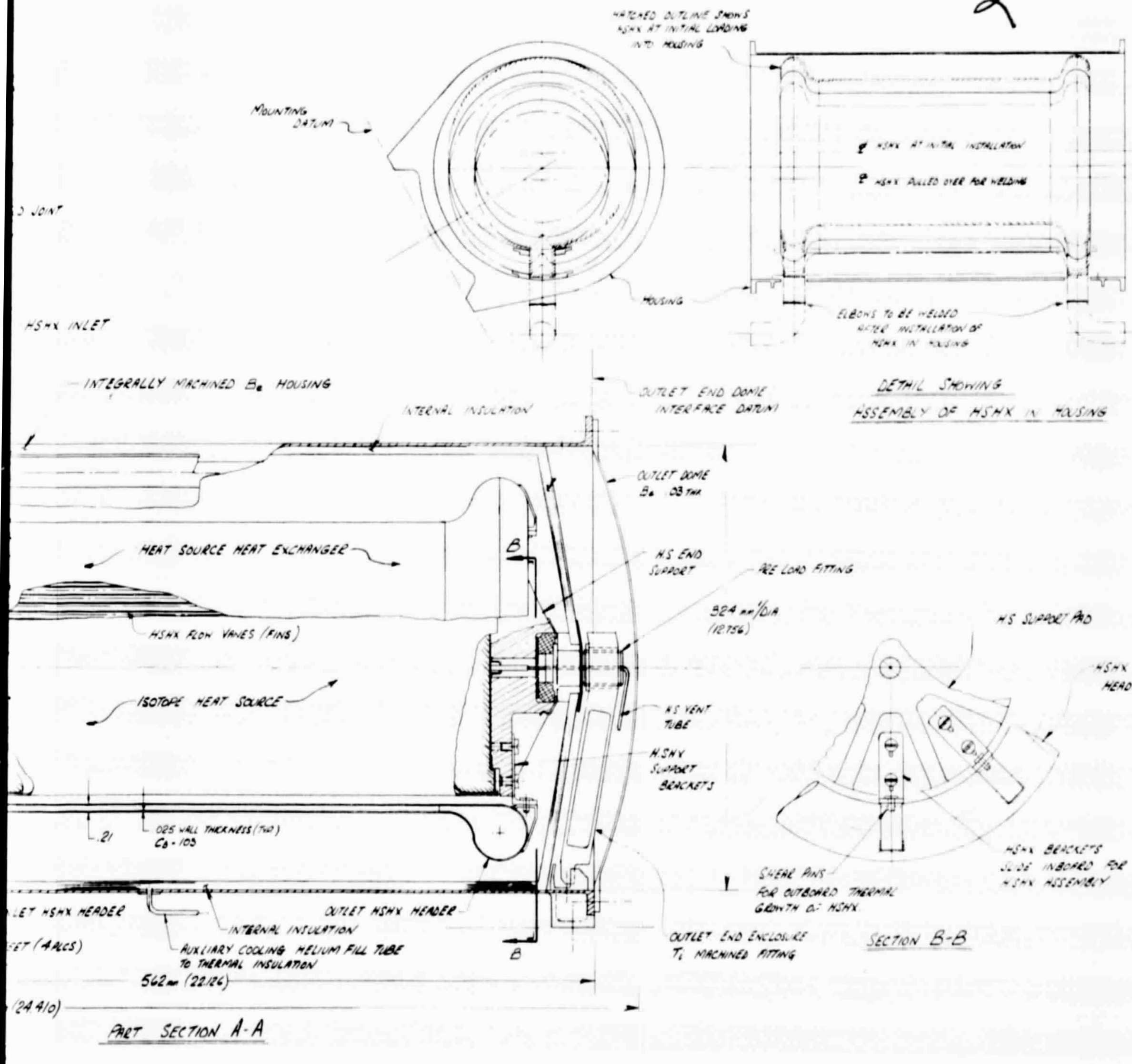


Figure 4-1. Reference Baseline HSA

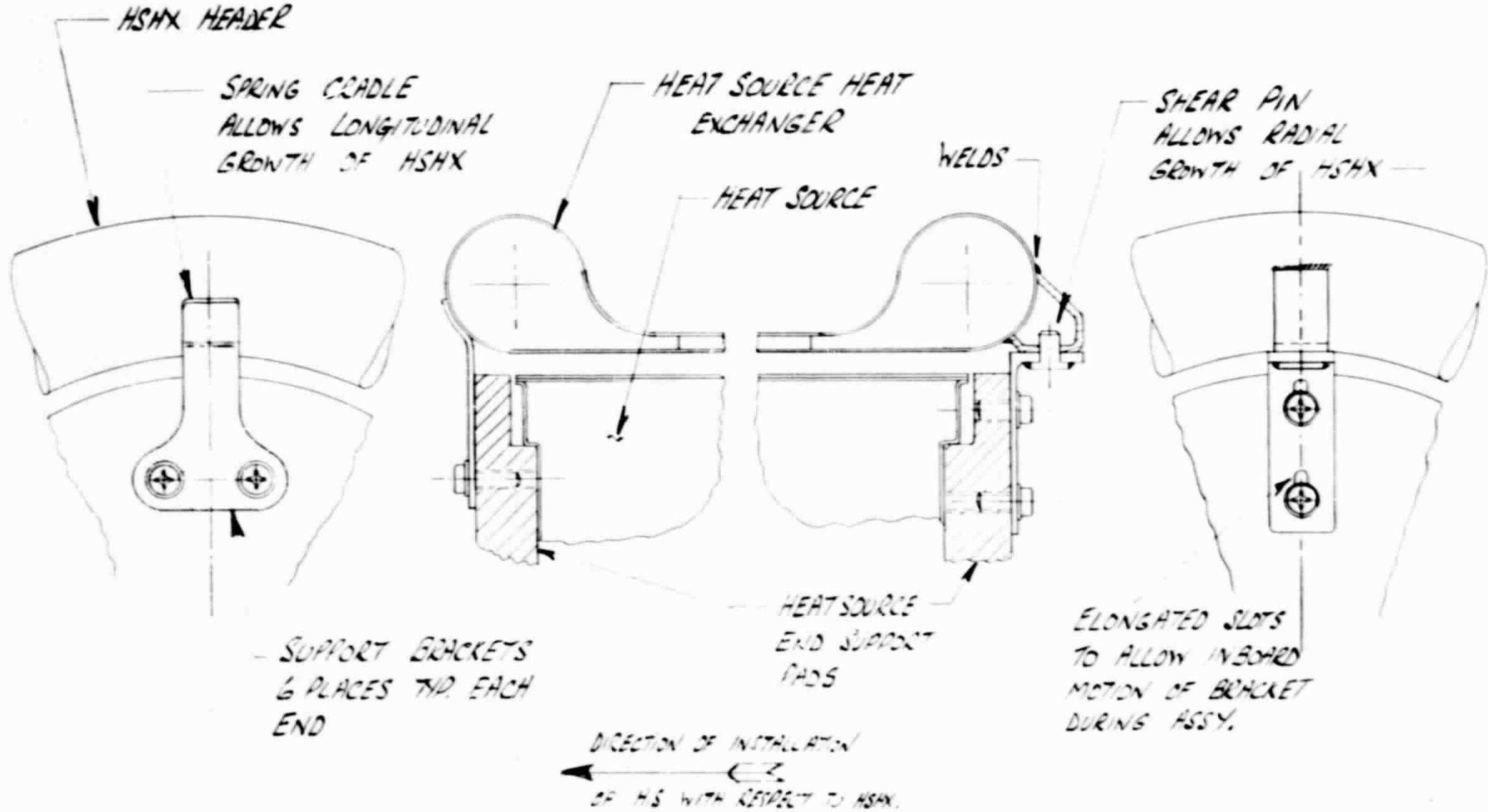


Figure 4-2. HSHX Mounting Support

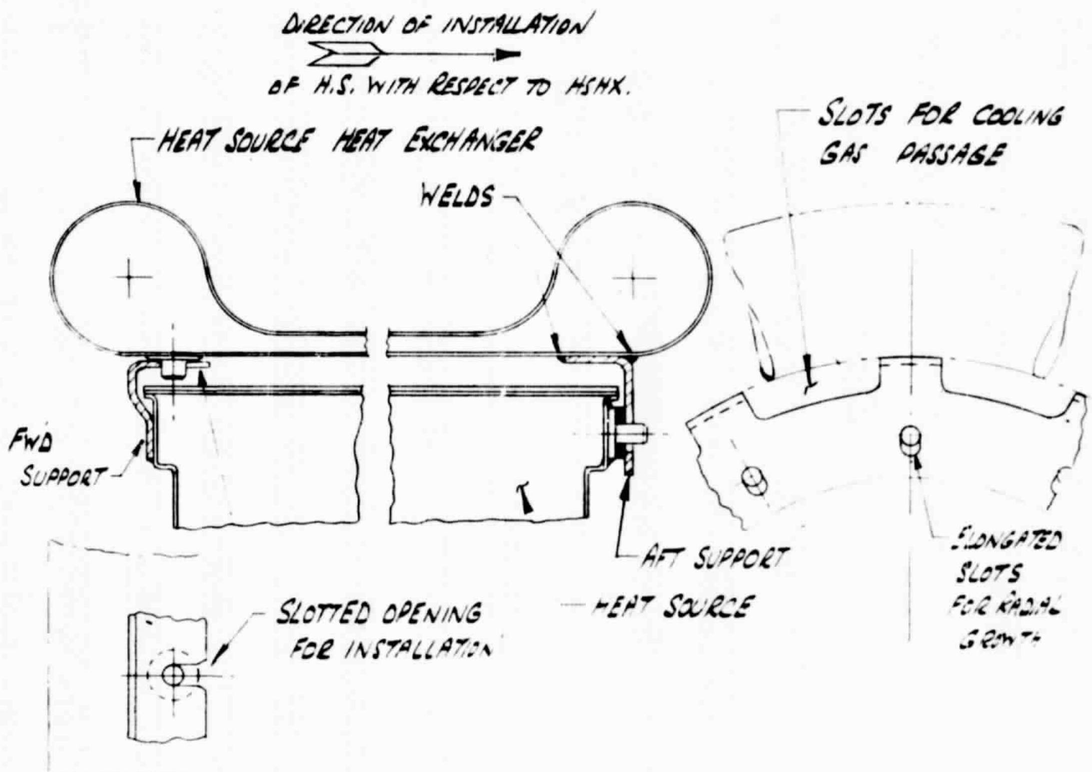


Figure 4-3. Alternate HSHX Mounting Support

designs. Both the spiders and the support housing are located in a relatively low temperature region external to the insulation blanket. Beryllium domes on both ends complete the support housing assembly. Mounting feet attachment fittings are provided on the beryllium support housing to provide the mechanical interface with the Mini-Brayton Power Conversion system. All launch loads are transmitted through the beryllium support housing.

The Heat Source Heat Exchanger (Cb-103 or Cbl-Zr) is shown in Figure 4-4. It is identical to the space shuttle plate fin design (Figure 11-1, Volume 1) except for reduced wall gauges, and a reduced length which permitted reduction of the overall HSA envelope. The HSHX contains five (5) machined fins per inch which we selected (in the space shuttle design study) on the basis of both fabrication and pressure drop considerations. The HSHX and header wall gauge are based on 1% creep stress limits in the longitudinal direction and 2% in the radial direction. The structural analysis takes credit for the support constraint provided by the bonded machined fins to the outer HSHX cylindrical wall. This constraint was not included in sizing the HSHX walls for the shuttle mission design where weight was not a significant parameter. The 0.025 inch wall gauges are actually fabrication limitations - sizing based on structural analysis would permit 0.020 inch cylindrical walls. An increase in the working fluid pressure to $79 N/cm^2$ (115 psi) would require an increase in the header walls to 0.050 inches. The HSHX cylindrical walls thickness would remain fixed at 0.025 inches.

Figure 4-5 shows the effect of working fluid pressure on HSHX weight (including the inlet and outlet toroidal headers). As can be seen, the weight penalty of 0.52 kG (2.3 lbs) to increase the design pressure from 41 N/cm^2 (60 psi) to 79 N/cm^2 (115 psi) is small.

The total HSA weight is 38.12 kG (84.05 lbs). If the HSA was designed for 79 N/cm^2 (115 psi) the total weight would be 39.14 kG (86.29 lbs). A weight breakdown is given in Table 4-1.

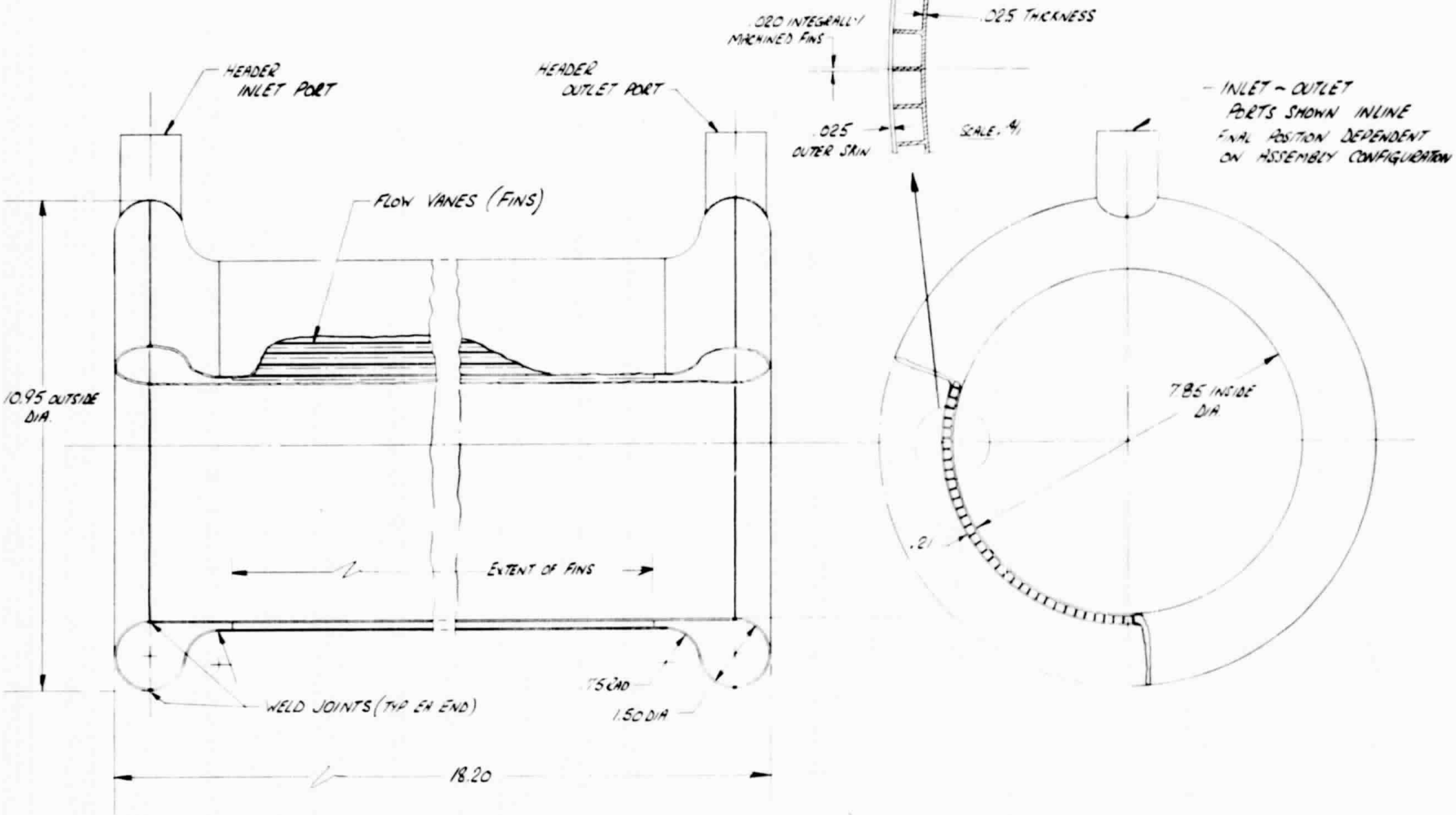


Figure 4-4. Heat Source Exchanger-Machined Plate Fin

Table 4-1. Reference Baseline HSA Weight Summary

Item	Weight - kG		Weight - Lbs	
Heat Source				
Basic MHW		21.55		47.5
Heat Source Heat Exchanger		4.95 [5.96]		10.91 [13.15]
Headers	1.02 [2.03]		2.24 [4.48]	
Walls	2.74		6.03	
Fins	0.95		2.10	
Ports	0.05		0.11	
Support Brackets	0.20		0.43	
HS Support		3.55	7.83	
End Enclosures (Spiders)	1.36		2.99	
Preload Screws	0.16		0.35	
Fitting (Spiders)	0.22		0.49	
HS Support Pads	0.91		2.00	
Misc. (Bushing, Disks, Etc.)	0.91		2.00	
HSA Support Closure Structure		3.32	7.31	
Cylinder Housing	2.41		5.31	
Domes	0.68		1.50	
Misc. Hardware	0.23		0.50	
Insulation		4.76	10.50	
Ends	1.18		2.6	
Cylinder	3.58		7.9	
HSA/Power System Interface Support Hardware	Integral with Housing			
Total HSA Weight - Lbs		38.12 [39.14]	84.05 [86.29]	

Note - Weight In[ ]are for 3 kW Mini-Brayton System (HSHX Pressure 79N/cm^2-(115 psi))

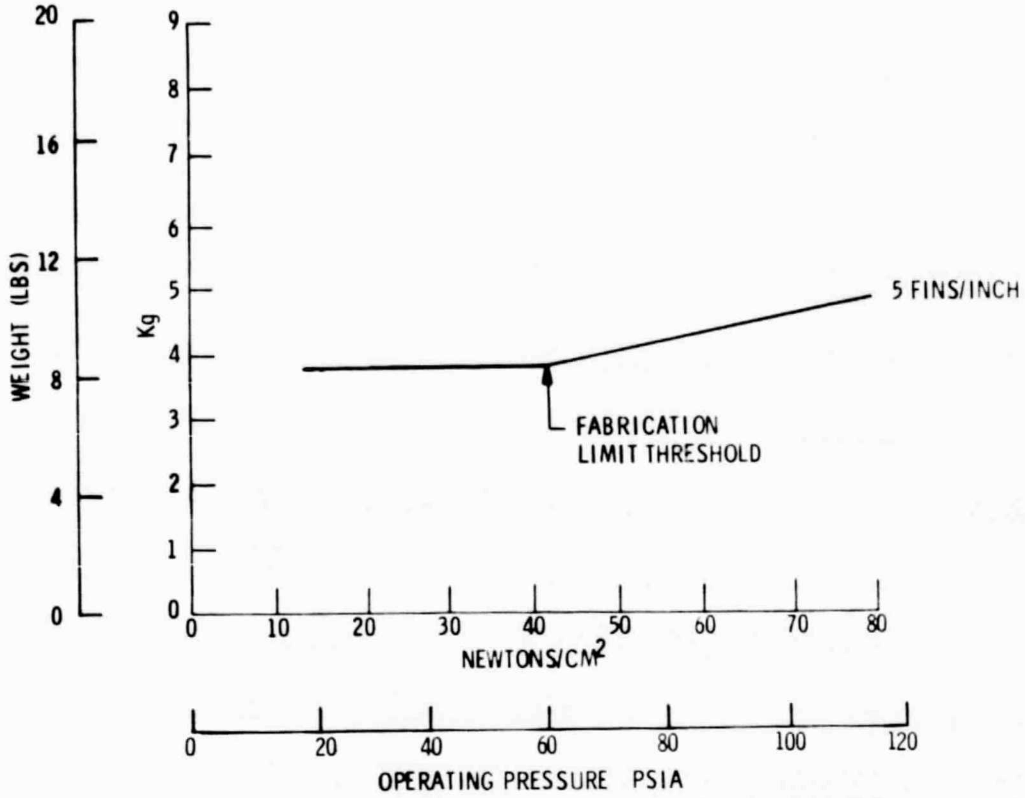


Figure 4-5. Mini-Brayton Heat Source Heat Exchanger-Effect of Pressure Level on HSHX Weight

Emergency cooling is effected by a zirconia coated nickel foil insulation blanket which melts at 1728 ^{O}K (2650 ^{O}F) in the event of a loss of working fluid flow or other system failure which causes an overtemperature of the heat source.

Auxiliary cooling on the launch pad is effected by thermally shorting the insulation blanket with an inert gas, e.g., helium.

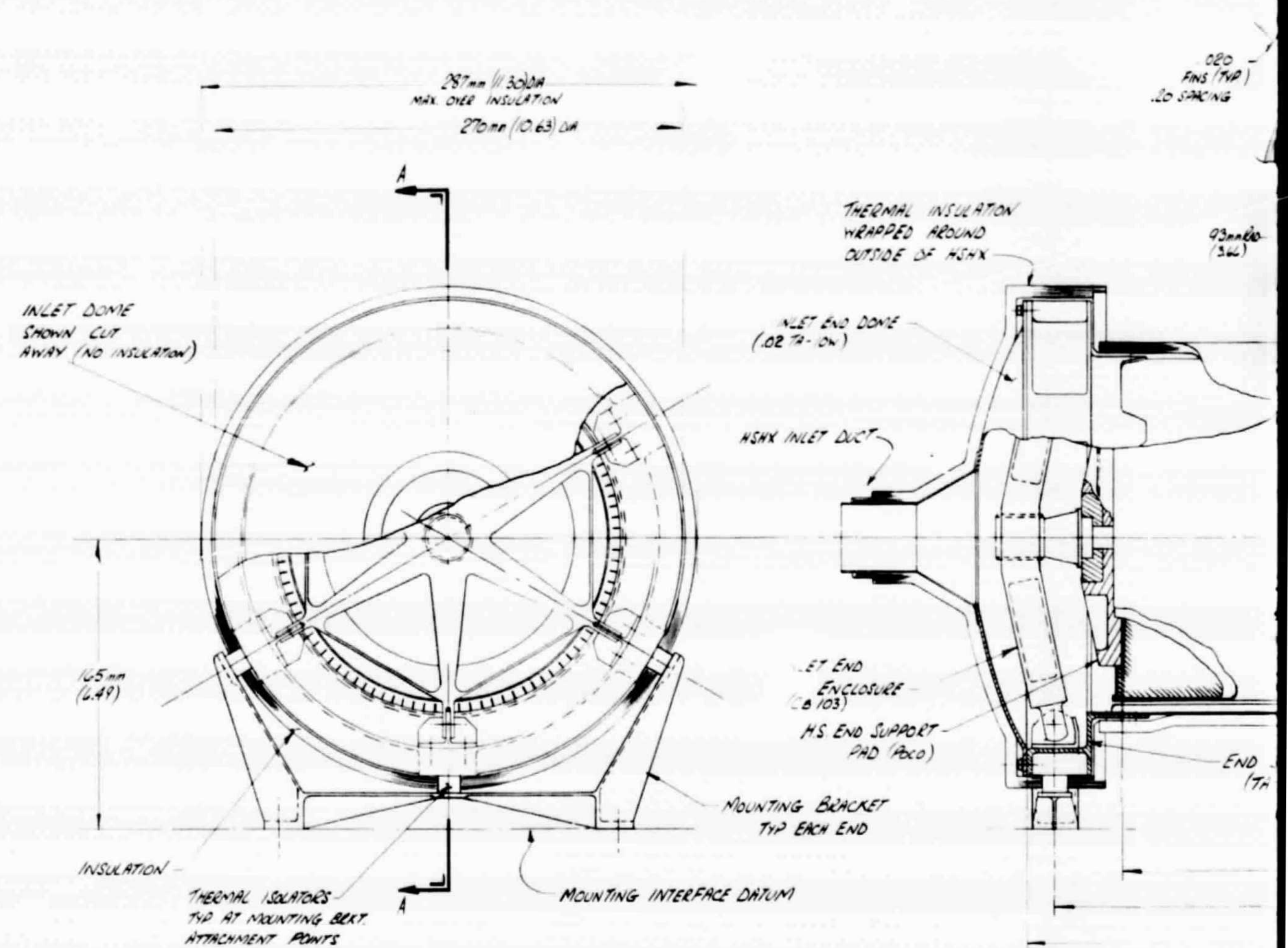
The Emergency Cooling and Auxiliary Cooling Subsystems are discussed in Section 6.

4.2 DIRECT COOLING HEAT SOURCE ASSEMBLY DESIGN (CONCEPT A)

The Direct Cooling HSA design shown in Figure 4-6 features the flow of Xe-He working fluid directly over the external surface of the heat source. As such, it requires that the HSA be a sealed unit. The design utilizes an integral HSHX that also serves as the primary launch load carrying structure and mounts directly to the Mini-Brayton Power

FOLDOUT FRAME

1



FOLDOUT FRAME

2

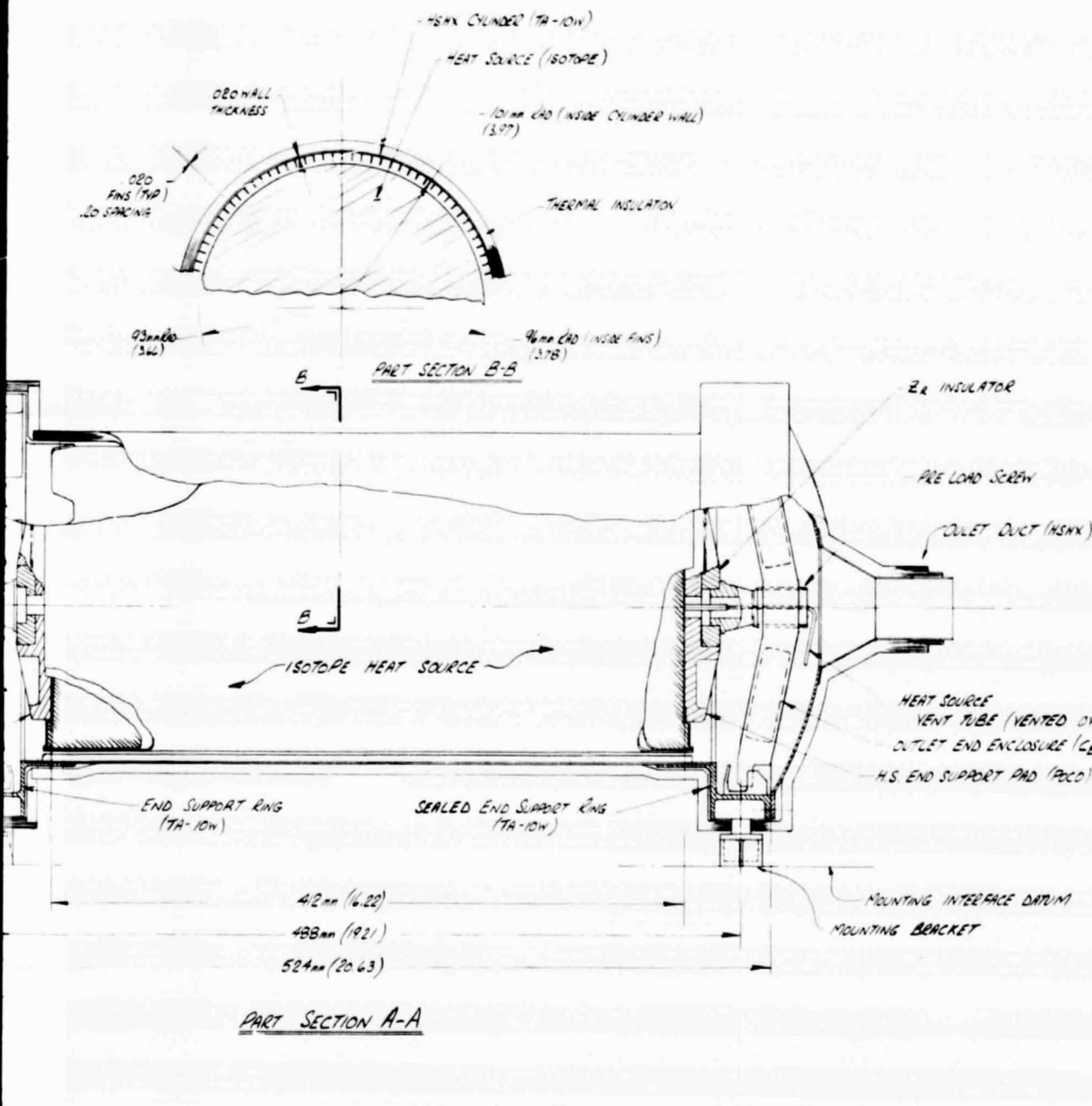


Figure 4-6. Concept A-Direct Cooling HSA

Conversion interface. A single cylindrical skin integral rib with machined fins surrounding the heat source, serves as the HSHX flow passage and no direct interface exists between the HSHX fins and the outer surface of the heat source (i.e., the fins don't touch the heat source girdle). This design results in considerably higher operating stresses than in the reference baseline HSA design,and analysis has shown that a high strength tantalum refractory alloy (TA-10W or T-111) would be required in order for this design to be weight competitive. Because the HSA must be sealed, the Heat Source End Enclosures (Spiders) are located in the high temperature region within the insulation blanket enclosure. As such, the spiders must be constructed from a refractory alloy, i.e., Cb-103 or Cb1-Zr which results in a higher short term creep rate than that which results with the baseline titanium spider. Analysis has shown that creep preload relaxation may be accounted for by setting the pre-launch pre-load within fifty (50) hours of launch. This imposes the constraint for sealing the HSA at the launch site and possibly after all other system ground testing and check out is completed.

The Emergency Cooling and Auxiliary Cooling Subsystems are identical to those described for the Reference Baseline HSA design in the previous section (4.1).

The Direct Cooling HSA weighs 40.31 kG (88.87 lbs) with an increase to 43.41 kG (95.71 lb) for a working fluid pressure of 79 N/cm^2 (115 psi). The weight breakdown for this design is given in Table 4-2.

4.3 MODIFIED BASELINE HSA DESIGN (CONCEPT B)

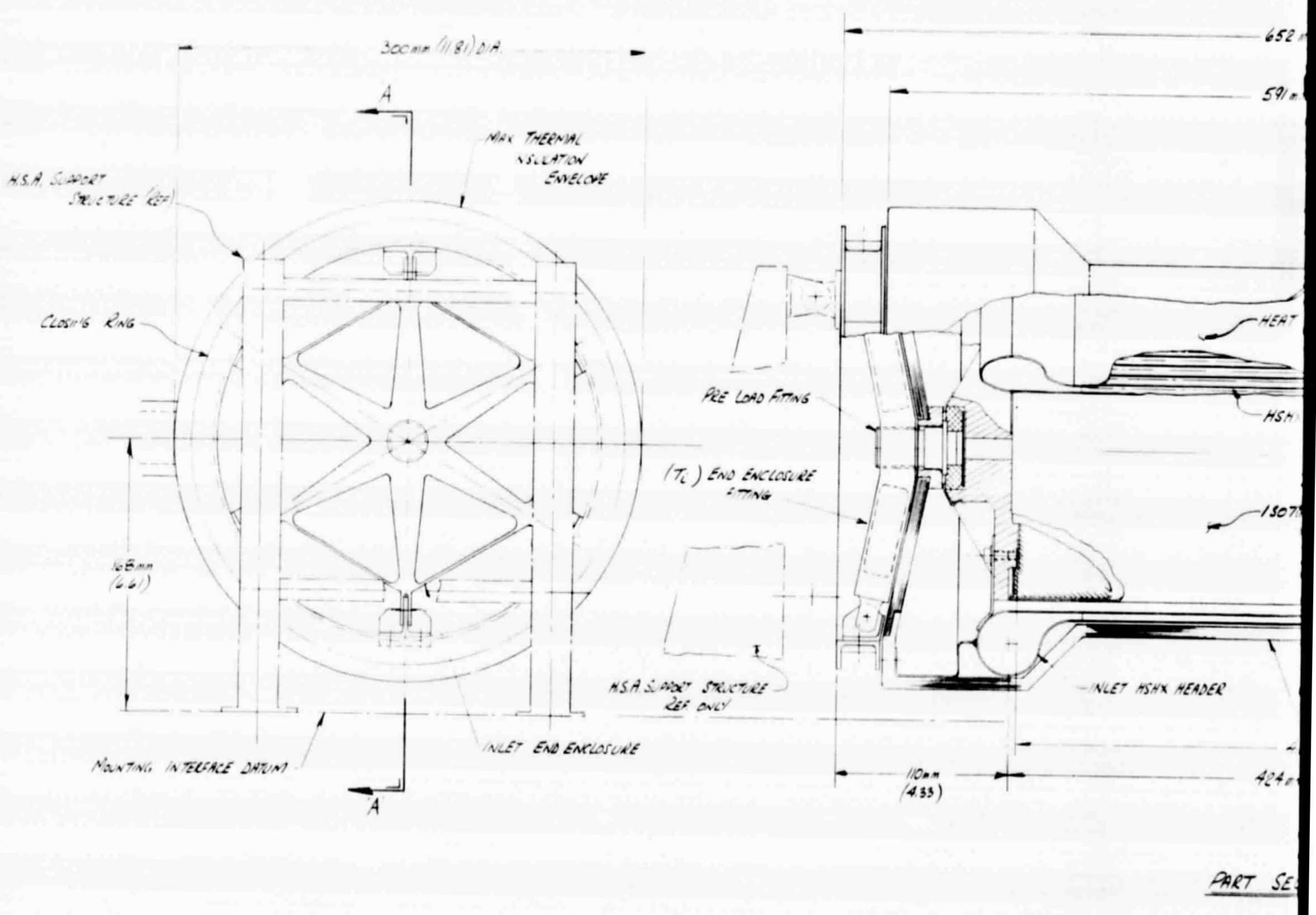
The modified baseline HSA concept shown in Figure 4-7 employs all of the essential features of the Reference Baseline HSA design by retaining the columbium alloy plate fin HSHX and supports, and heat source titanium end enclosures (spiders). The principle difference is that HSA support and transfer of launch loads are integrated into the Mini-Brayton Power Conversion System (PCS) backup structure (which is undefined). The beryllium HSA support housing is thus eliminated. As such, the unit is not self-contained and self-supporting as is the reference baseline design and preload must be developed at installation and integration with the PCS. In order to minimize weight

Table 4-2. Direct Cooling HSA Weight Summary

Item	Weight - kG		Weight - Lbs	
Heat Source		21.55		47.5
Basic MHW				
Heat Source Heat Exchanger		4.59 [7.28]		10.13 [16.04]
Headers	N/A		N/A	
Walls	2.68 [5.09]		5.91 [11.22]	
Fins	1.81		4.	
Ports	0.10		0.22	
Support Brackets	N/A		N/A	
HS Support		4.75		10.47
End Enclosures (Spiders	2.36		5.2	
Preload Screws	1.52		3.35	
Fitting (Spiders)	0.52		1.15	
HS Support Pads	0.79		1.75	
Misc. (Bushing, Disks, Etc.)	0.91		2.00	
HSA Support Closure Structure		5.02 [5.44]		11.07 [12.00]
End Rings	4.16		9.17	
Domes	0.64 [1.06]		1.40 2.33	
Misc. Hardware	0.23		0.5	
Insulation		4.04		8.9
Ends	1.09		2.4	
Cylinders	2.95		6.5	
HSA/Power System Interface Support Hardware		0.36		0.8
Total HSA Weight		40.31 [43.14]		88.87 [95.71]

Note - Weight in[ ]are for 3 kW Mini-Brayton System (HSHX Pressure 79N/cm^2 - (115 psi))

FOLDOUT FRAME



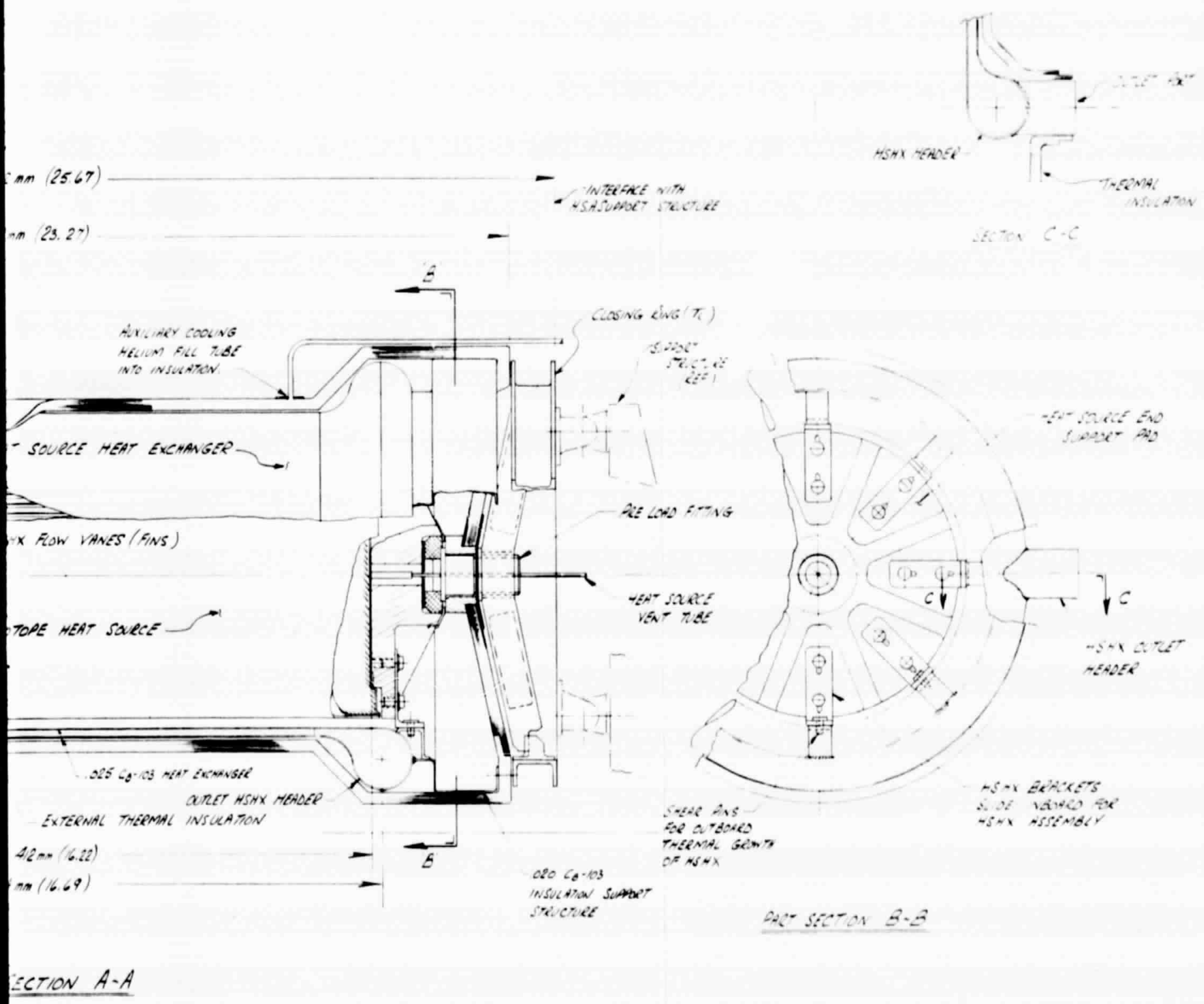


Figure 4-7. Concept B-Modified Baseline HSA

further, the HSA envelope was reduced by reconfiguring the titanium spiders to cant longitudinally outward, and the insulation blanket diameter reduced to the diameter of the HSHX. This design approach results in the lowest weight HSA of those studied, however, the design constrains the HSA launch orientation so that the booster longitudinal axis is normal to the HSA axis.

Emergency Cooling and Auxiliary Cooling Subsystems are identical to those described for the reference baseline HSA.

The HSA weight for this design is 35.46 kG (78.17 lb) which increases to 36.47 kG (80.41 lbs) for a working fluid pressure of 79 N/cm^2 (115 psi). The weight breakdown is given in Table 4-3.

4.4 INTEGRAL SUPPORT HSA DESIGN (CONCEPT C)

The Integral Support HSA design shown in Figure 4-8 utilizes the HSHX as the primary HSA support and launch load carrying structure. The HSHX core (cylinder section) is a columbium alloy plate fin design similar to the reference baseline HSHX configuration. The inlet header, however, has a different cross sectional shape and must be fabricated from a high strength refractory alloy (TA-10W or T-111) to sustain the loads and minimize weight. On the outlet end, the working fluid is manifolded into a double wall tantalum alloy dome shaped header and thence to the outlet port. The heat source is loaded into the HSA from the inlet side and seated on four support pad bearing mounts and preload is developed integrally with the HSHX at the opposite end by a modified spider arrangement. The bearing mounts interface with a conical frustum titanium HSA support structure. The HSA support structure provides the mechanical interface with the Mini-Brayton PCS.

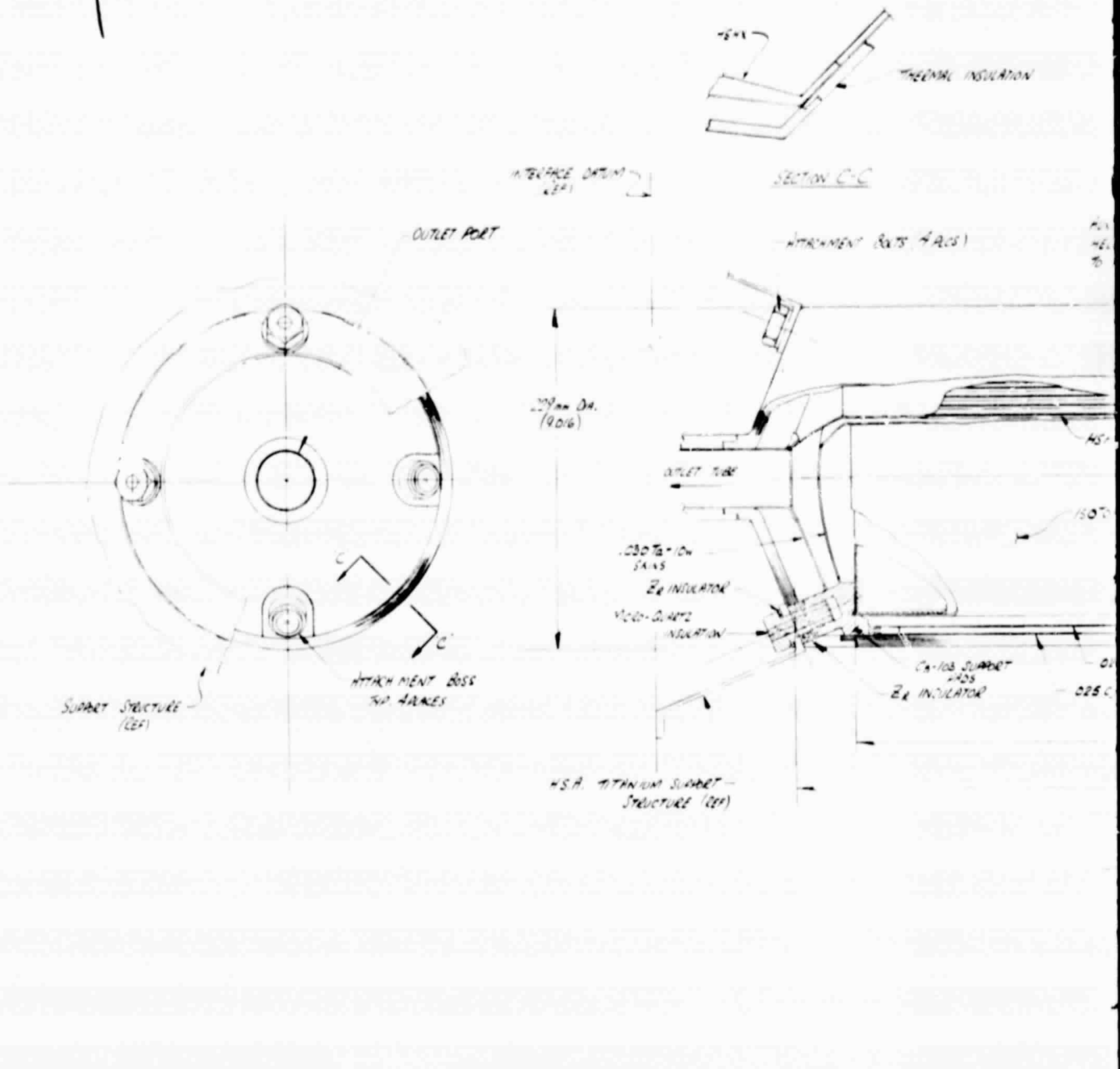
The concept as shown is designed for mounting the HSA major axis along the booster longitudinal axis. The dome shaped header must be sealed at the bearing mount support penetrations.

Table 4-3. Modified Baseline HSA Weight Summary

Item	Weight - kG		Weight - Lbs	
Heat Source		21.55		47.5
Basic MHW				
Heat Source Exchanger		4.95 [5.96]		10.91 [13.15]
Headers	1.02 [2.03]		2.24 [4.48]	
Walls	2.74		6.03	
Fins	0.95		2.10	
Ports	0.05		0.11	
Support Brackets	0.20		0.43	
HS Support		3.10		6.84
End Enclosures (Spiders)	0.91		2.00	
Preload Screws	0.16		0.35	
Fitting (Spider)	0.22		0.49	
HS Support Pads	0.91		2.00	
Misc. (Bushing, Disks, Etc.)	0.91		2.00	
HSA Support Closure Structure		1.49		3.29
Cylindrical Housing	N/A		N/A	
Insulation Supports	0.68		1.49	
Closing Rings	0.59		1.30	
Misc. Hardware	0.23		0.50	
Insulation		4.37		9.63
Ends	0.97		2.13	
Cylinder	3.4		7.5	
HSA/Power System Interface Support Hardware	N/A		N/A	
Total HSA Weight		35.46 [36.47]		78.17 [80.41]

Note - Weight in [ ] are for 3 kW Mini-Brayton System (HSHX Pressure 79 N/cm^2-(115 psi))

FOLDOUT FRAME



FOLDOUT FRAME

2

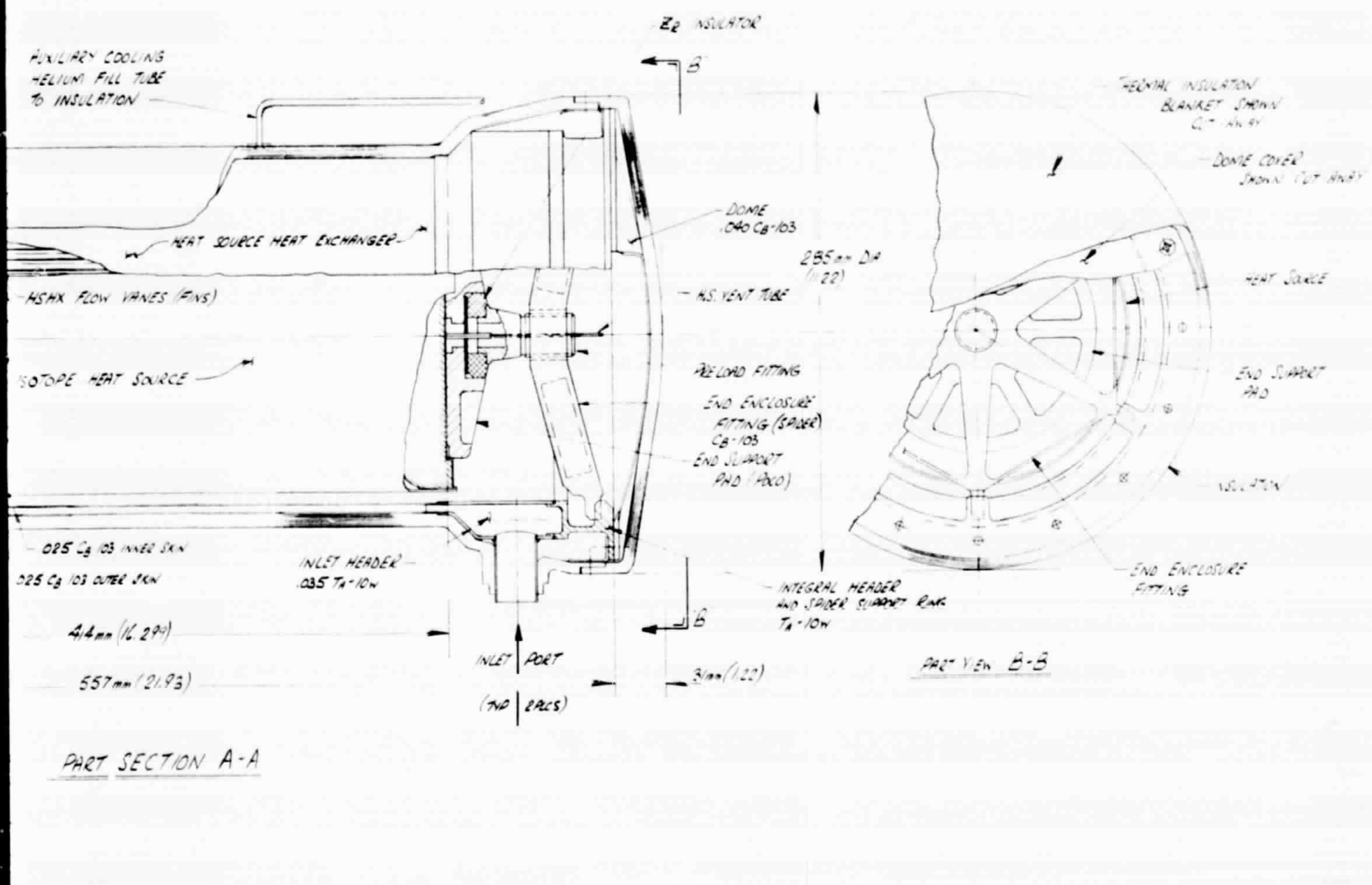


Figure 4-8. Concept C-Integral Support HSA

The Emergency Cooling and Auxiliary Cooling Subsystems are identical to the reference baseline design.

The weight of the integral support design is 38.66 kG (85.24 lb) with a growth to 40.33 kG (88.91 lb) for a pressure of 79 N/cm^2 (115 psi). The weight breakdown is given in Table 4-4.

4.5 HSA TRADE-OFF

Selection of a preferred "minimum weight" concept for the Titan III C mission was based on the following criteria.

1. Weight: The HSA weight at the design point of 41 N/cm^2 (60 psi) as well as the weight increment for a pressure level of 79 N/cm^2 (115 psi) was evaluated.
2. Heat Source Temperature: Low heat source temperatures provide a larger safety margin.
3. HSHX Flow Distribution and Stability: Clearly, flow distribution and flow stability effect performance of the heat exchanger. These criteria were evaluated qualitatively.
4. Heat Source Modification Requirements: Requirements for heat source modifications have an impact on cost.
5. Launch Orientation Constraints: Lack of an orientation constraint provides flexibility in Mini-Brayton system design and integration.
6. Handling/Test Pad Checkout: The ability to easily remove and reload the heat source during test and checkout cycles and to be capable of sustaining holds during the countdown without requiring HSA disassembly, is highly desirable.
7. Fabrication: Ease of HSHX fabrication and reliability of fabrication procedures can impact HSHX failure modes.
8. Development Consideration: Both cost and schedule are affected by development requirements.
9. Integration with Mini-Brayton Power Conversion System or Spacecraft: Well defined HSA mechanical interfaces independent of definition of other spacecraft or Mini-Brayton system components are highly desirable. Complex interface dependence affect cost and invariably weight and technical complexity.

Table 4-5 is a trade-off matrix which summarizes the evaluation of the four candidate HSA designs using the above criteria. Overall, the reference baseline is considered to be the preferred design. It is the second lightest in design and probably the lightest, if one penalizes the modified baseline design for the weight of the yet undefined mechanical

Table 4-4. Integral Support HSA Weight Summary

Item	Weight - kG		Weight - Lbs	
Heat Source		21.55		47.5
Basic MHW				
Heat Source Heat Exchanger		6.33 [7.57]		13.96 [16.68]
Headers	1.27 [1.81]		2.80 [4.0]	
Walls	2.74 [3.43]		6.05 [7.57]	
Fins	0.95		2.10	
Ports	0.10		0.21	
Support Brackets	1.27		2.80	
HS Support		3.57		7.88
End Enclosures (Spiders)	2.40		5.30	
Preload Screws	0.08		0.18	
Fitting (Spider)	0.24		0.53	
HS Support Pads	0.45		1.00	
Misc. (Bushing, Disks, Etc.)	0.45		1.00	
HSA Support Closure Structure		3.31 [3.74]		7.30 [8.25]
Cylindrical Housing	N/A		N/A	
Domes	0.64 [1.08]		1.42 [2.37]	
Insulation Support	0.36		0.80	
Closing Rings	2.08		4.58	
Misc.	0.23		0.50	
Insulation		3.9		8.6
Ends	0.82		1.80	
Cylinder	3.08		6.80	
HSA/Power System Interface Support Hardware	N/A		N/A	
Total HSA Weight		38.66 [40.33]		85.24 [88.91]

Note - Weight in [ ] are for 3 kW Mini-Brayton System (HSHX Pressure 79 N/cm^2 -(115 psi))

system interface hardware. Flow distribution and stability is well defined. It's HSHX utilizes a single refractory alloy (Cb-103 or Cb1-Zr) and does not require any bimetallic joints within the HSA unit. Fabrication is relatively straightforward. It offers flexibility in launch orientation, handling, testing, checkout and integration with the Mini-Brayton system. Since no seal is required, the heat source (electrical or isotope) can be readily removed and reloaded during testing. Pre-load can be set well before launch with virtually no time constraints. It utilizes MHW technology, hardware, and ground support equipment to the maximum extent possible, thus resulting in lowest development costs.

Since the reference baseline HSA is the preferred approach, the section that follows will address only that design.

Table 4-5. HSA Design Tradeoff

Criteria	Preferred Design Reference Baseline	Concept A Direct Cooling	Concept B Modified Baseline	Concept C Integral Support HSHX
Weight **Delta for 2kW Growth**	38 kG (84 lb) 1.0 kG (2.3 lb)	40 kG (89 lb) 3.2 kG (7 lb)	35 kG (78 lb) 1.0 kG (2.3 lb) - Lowest Weight	39 kG (85 lb) 1.7 kG (3.7 lb)
Heat Source Surface Operational Temp	1269°K (1825°F)	1227°K (1750°F) - Lowest HS Temperature	1269°K (1825°F)	1269°K (1825°F)
HSHX Flow Distribution and Stability	Excellent	Less Well Defined-Cross Flow Possible	Excellent	Excellent
Heat Source Modification Requirements	None	Iridium & Graphite End Cap Redesign	None	Iridium & Graphite End Cap
Launch Orientation Constraint	None	None	Horizontal Only	Vertical (Adaptable to Horizontal with Modifications)
Handling/Test/Pad Checkout	Heat Source Easily Removed During Ground Test Program	Preload Must be Set Within 50 Hr of Launch HSA must be Sealed (50 Hr Prior to Launch) HSA Seals Broken and Resealed During Ground Test Program Does not Permit Auxiliary Cooling Flow Over Heat Source	Heat Source Easily Removed During Ground Test Program GSE Handling Fixture Required to Provide Preload Interface and HSA Support During Handling and Test	Preload must be Set Within 50 Hr of Launch Heat Source Easily Removed During Ground Test Program
Fabrication	Cb-103; Cb1-Zr--Good Weldability and Forming	TA-10W--Good Weldability, Slightly more Difficult to Form than Columbium	Cb-103; Cb1-Zr--Good Weldability and Forming	Requires Welding or Brazing of Cb/TA-10W Bi-Metallic Joint
Development Considerations	Similar to MHW-RTG Installation Minimum Change to HS Support Components Commonality with MHW Handling and Test Fixtures Lowest Development Cost	HS Support Approach Requires Characterization of Spider/HS Preload Short Term Creep Effect	Minimum Change to HS Support Components Characterization of PCS Interface Required No Commonality with MHW-RTG Handling and Test Fixtures	Characterization of New HS Support System Required Characterization and Fabricability of HSHX Bimetallic Joints New Approach Requires Characterization of Spider HSHX Preload Short Term Creep Effect
Integration with Mini-Brayton Power Conversion System or Spacecraft	Straight Forward Structural Interface	Straight Forward Structural Interface	Requires HS Loading on PSC or Spacecraft HS Preload must be Integral with PCS or Spacecraft Interface	Straight Forward Structural Interface

SECTION 5

HSA PERFORMANCE

SECTION 5

HSA PERFORMANCE

5.1 HYDRAULIC PERFORMANCE

As indicated in Section 8.2 of Volume I, the HSHX flow channels are sized for a pressure drop of approximately $0.69 N/cm^2$ (0.1 psi) so that a relatively large percentage of the total pressure drop in the HSA occurs within the core of the HSHX. This assures good flow distribution within the HSHX. Figure 5-1 shows pressure drop and heat source surface temperature as a function of radial flow gap and the machined fin spacing. The design point of 5 fins/inch and an annular gap of 0.41 cm (0.16 in.) was selected on the basis of the pressure drop criterion above and on fabricability (machining) considerations. The resultant maximum Heat Source surface temperature is 1269^oK (1825^oF).

5.2 THERMAL PERFORMANCE

The predicted temperature distribution along the HSHX wall and Heat Source is given in Figure 5-2. Temperatures for emissivities of $\epsilon = 0.4$ and 0.8 on the HSHX wall facing the Heat Source, are given. An emissivity of $\epsilon = 0.4$ corresponds to grit blasting the HSHX surface; to obtain an emissivity of $\epsilon = 0.8$ which would reduce Heat Source temperatures by approximately 30^oK (54^oF) would require a coating.

A comparison of Heat Source temperatures for the MHW-RTG and the Mini-Brayton HSA is given in Figure 5-3. In the reference baseline HSA the Heat Source operates approximately 56^oK (100^oF) lower than in the MHW-RTG. This HSA operational PICS temperature is 221^oK (398^oF) lower than specification limits.

5.3 STRUCTURAL PERFORMANCE

The Heat Source Heat Exchanger is designed to exhibit not more than 1% axial creep after 5 years at operational temperatures in orbit.

The Heat Source is preloaded prior to launch to sustain 50 g launch loads. Creep of the titanium spider is only 0.010% in 50 hours or in terms of a 5 year life results in a preload

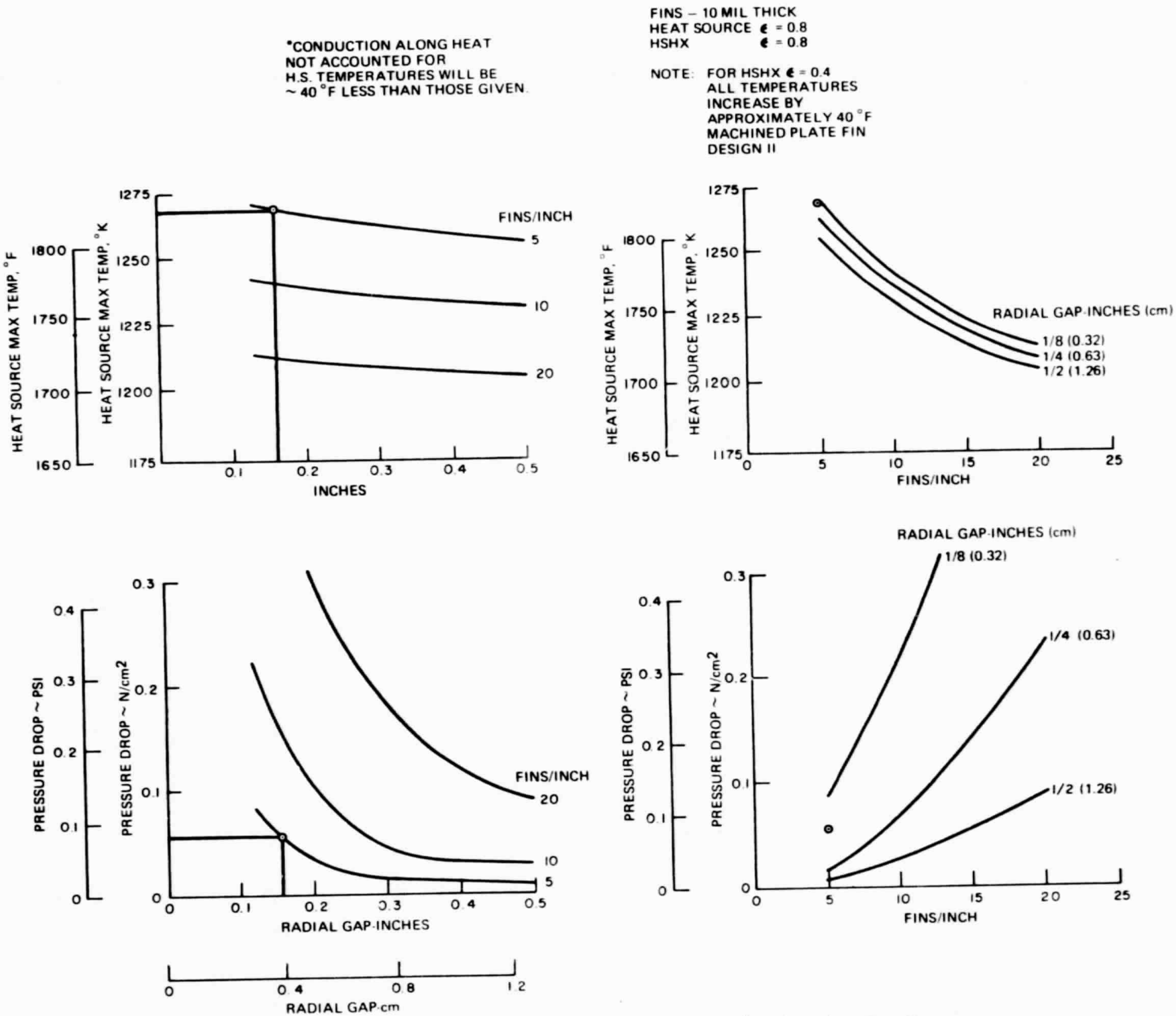


Figure 5-1. Plate Fin HSHX Thermal/Hydraulic Performance

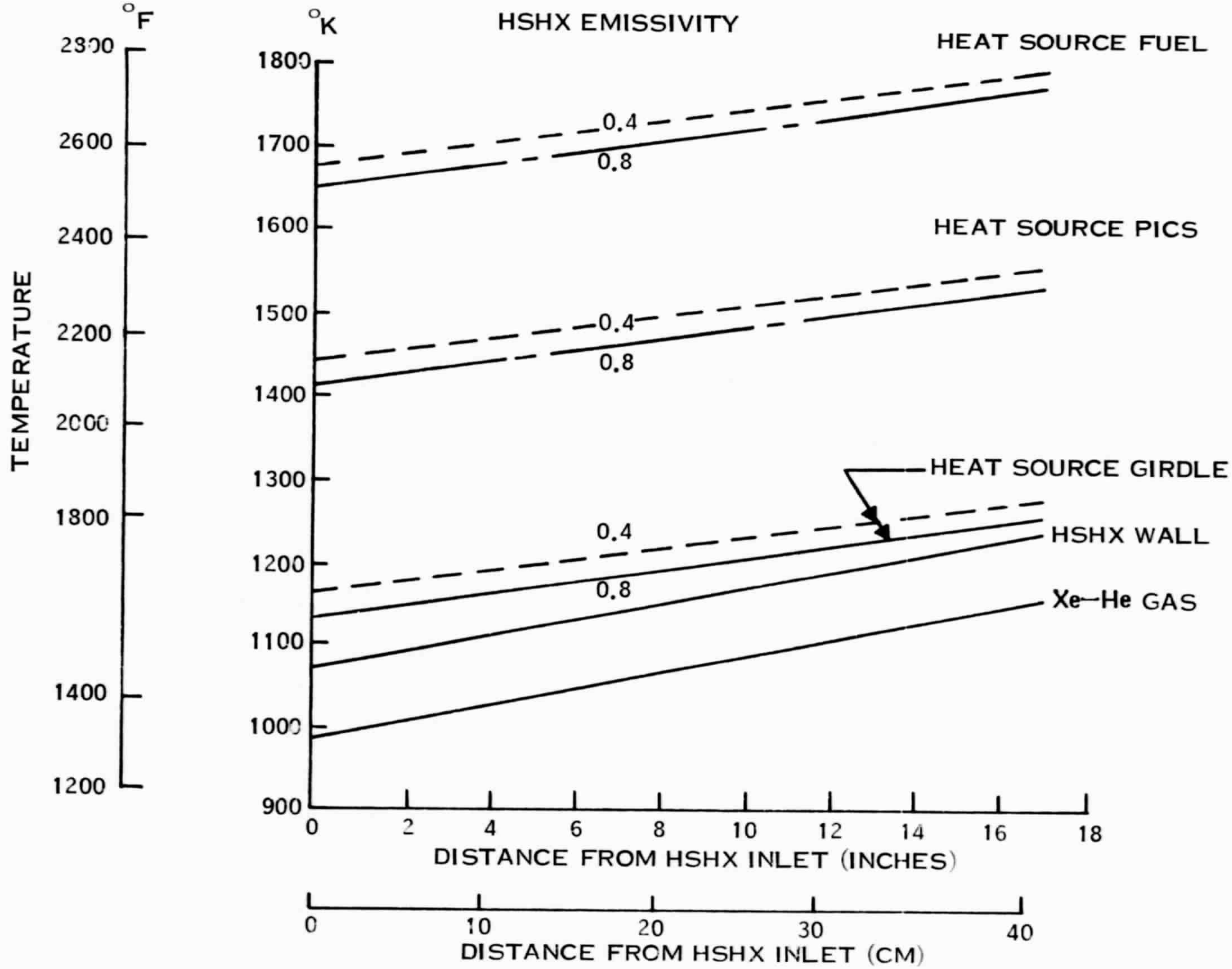


Figure 5-2. Axial Temperature Distribution

relaxation of only 500 lb. As such, the Heat Source can be loaded into the HSA well in advance of launch. The MHW titanium spider design utilized in the HSA has a strength capability of 6500 lbs, well above the 3600 lb preload required for launch.

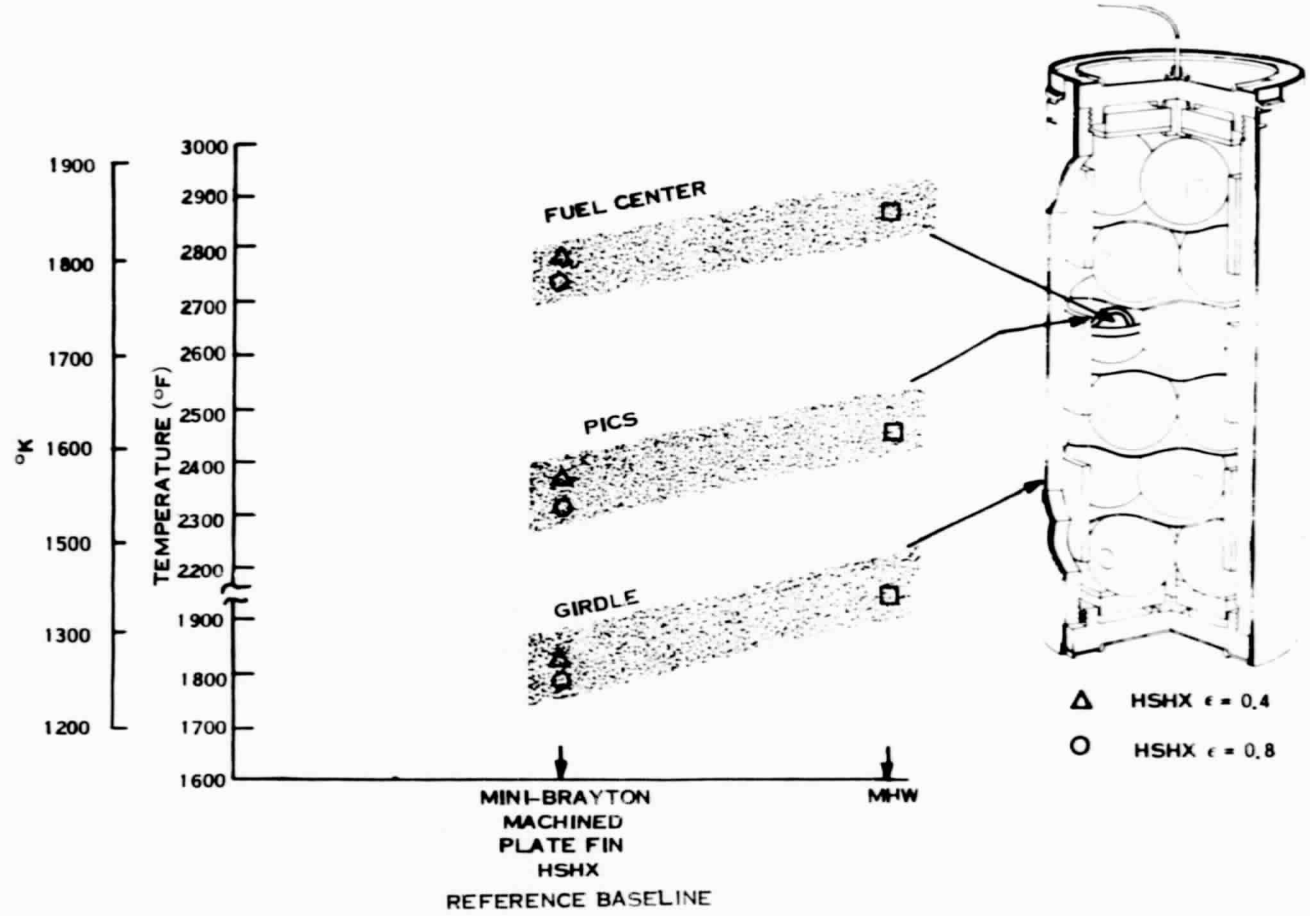


Figure 5-3. Mini-Brayton - MHW Heat Source Operational Temperature Comparisons

SECTION 6

SUBSYSTEMS

SECTION 6
SUBSYSTEMS

6.1 EMERGENCY COOLING SUBSYSTEM

6.1.1 REQUIREMENTS

Unlike static RTG's, dynamic nuclear power systems are designed to retain the thermal energy within the HSA. The only mode of heat removal in the basic system is by the flow of working fluid through the HSHX. The Emergency Cooling Subsystem (ECS) is designed to maintain safe Heat Source temperatures in the event of a failure of this primary working mode. The design requirements for the ECS are as follows:

1. Limit the maximum transient Heat Source Post Impact Containment Shell (PICS) to 2732°K (3810°F)

2. Limit the maximum steady state PICS temperature to 1773°K (2732°F)

As indicated in Sections 2 and 4, meltdown of the insulation blanket in an emergency situation has been selected as the ECS. To establish feasibility of this system,preliminary analysis were made of the insulation meltdown phenomenon.

6.1.2 TEMPERATURE RESPONSE

A ten-node, one-dimensional thermal model was developed for the analysis. It was assumed that once a failure of the Mini-Brayton system took place, all of the energy generated by the heat source is transferred through the insulation blanket and radiated to space.

The effects of "effective thermal conductivity" of the insulation, melt temperature, the mass-specific heat parameter, and emissivity of the external insulation surface, on melt time were examined.

The first analysis performed was for the purpose of determining if tailoring of materials is possible to effect melting of the blanket uniformly across its thickness at the onset of a failure. Figure 6-1 shows the transient response of the insulation with the simplifying assumption that material does not melt or sublime. It is clear that while the layers adjacent to the heat source respond quickly to a sudden energy input from the heat source, the middle and outer layers are not affected until minutes later.

Consequently it does not appear possible that tailoring the materials with progressively lower melting temperatures from the inner layers outward, will result in a uniform melting situation. The next step in the analysis was to determine how long it takes for melting to propagate through the insulation blanket.

Figure 6-2 gives the transient response after onset of a failure of an insulation blanket having the following properties:

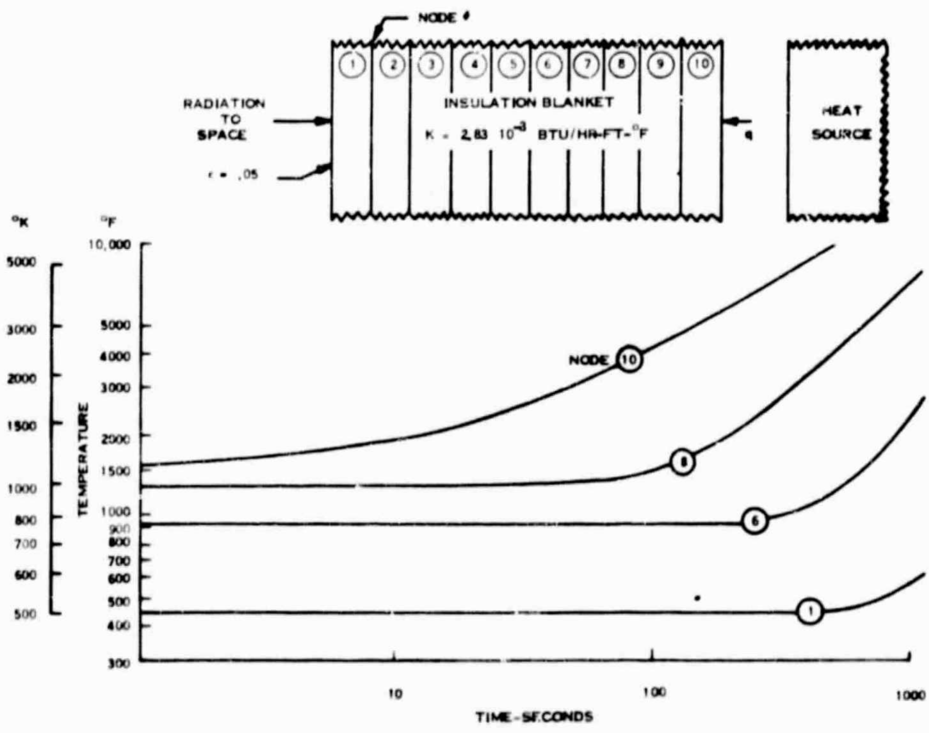


Figure 6-1. Transient Temperature Response of Insulation Blanket Without Melting

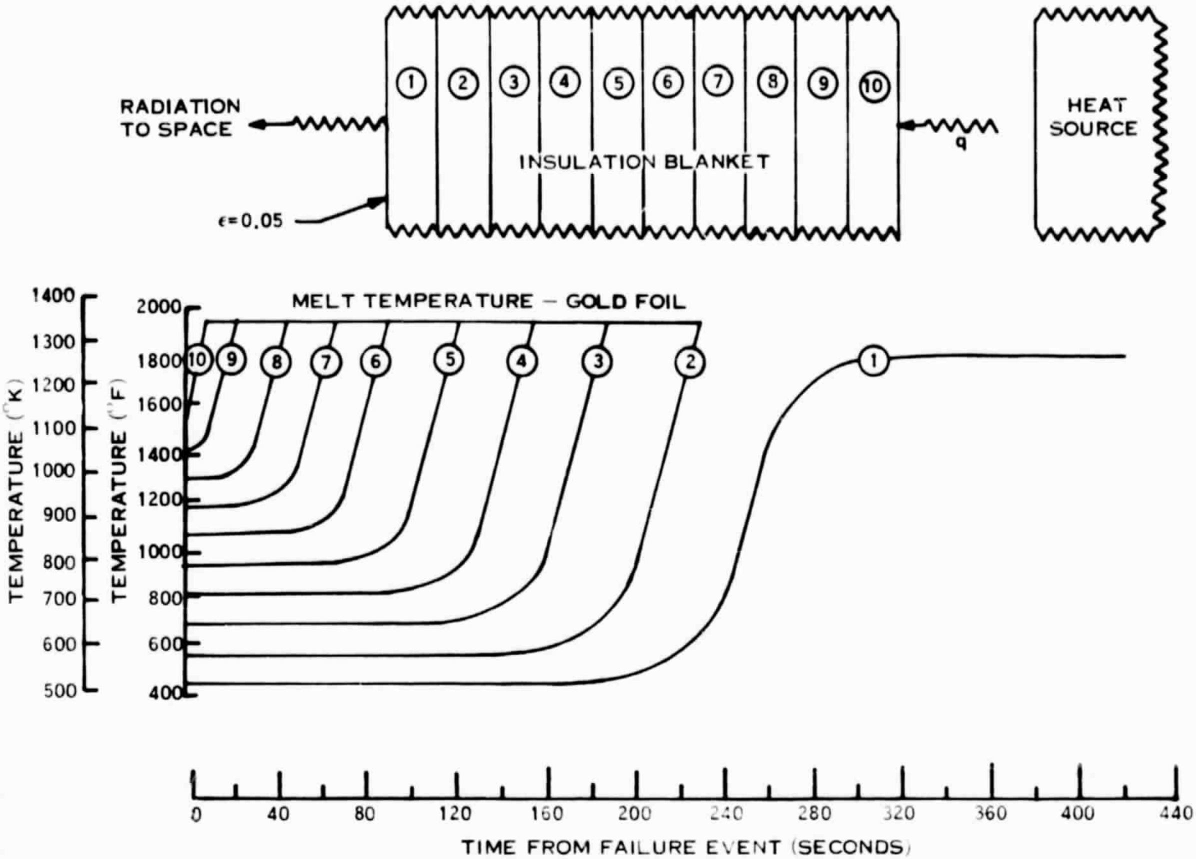


Figure 6-2. Transient Temperature Response of Melting Insulation Blanket

1. Effective Thermal Conductivity $K = 2.88 \times 10^{-3} \dfrac{\text{Btu}}{\text{Hr-Ft} - {}^{o}\text{F}}$

   This value of K is one half of the value that was backed out of test data for the MHW insulation blankets.

2. Melt Temperature $= 1339^{o}$K (1950^{o}F)

   This melt temperature was assumed to be a reasonable design goal based on an estimate of an equilibrium temperature of approximately 1550^{o}F at the inner layer of the insulation blanket during normal operation. It allows a 400^{o}F margin before melting will occur. Gold foil would be a candidate material for this application.

3. Emissivity of outer layer $\epsilon = .05$

   A low value on the insulation blanket is desirable to reduce the heat loss during normal operation.

It is evident from Figure 6-2 that the inner layers of the blanket responds with a rapid rise in temperature and reaches the melting temperature in 10 seconds. Melting progress

through the blanket until after approximately 230 seconds (< 4 minutes) all but the last node (#1) has melted. At this time, an equilibrium situation is established, with Node #1 at a temperature of 1255°K (1800°F) i.e., less than the melt temperature of 1339°K (1950°F). A 1255°K (1800°F) sink temperature for the Heat Source will preclude excessive heat source temperatures and thus represents an acceptable situation. As an option, the outer layers of the blanket could be selected of a material with a lower melting temperature so that the complete insulation blanket melts. For example, if the layers comprising Node #1 were aluminum foil (T_{melt} = 933°K (1220°F), the complete blanket would melt in approximately 255 seconds (< 4.5 minutes). A conservative estimate for the rate of temperature rise of the heat source is 700°F hr, consequently, during the time it takes to melt through the insulation blanket, the heat source experiences a very moderate increase in temperature (~ 50°F). Clearly there is a very large margin of safety inherent in such a moderate heat source temperature rise above the set point at which the emergency cooling is designed to activate.

It is interesting to note again that as the inner layers of the insulation blanket rise in temperature and melt, the outer layers lag well behind and don't respond until the node adjacent to it begins to rise in temperature and melt.

Figure 6-3 shows the temperature profile and melt times for an insulation blanket with a melt temperature of 1728°K (2650°F) corresponding to Nickel. The results are essentially the same as those above; the total time to melt through mode 2 is approximately 315 seconds (< 6 minutes).

6.1.3 SENSITIVITY ANALYSIS

The effect of insulation blanket properties on the time to melt through the insulation was investigated. Figure 6-4 shows that an order of magnitude variation in effective thermal conductivity has a very small influence on melt time (~ 25 seconds). Similarly, as shown in Figure 6-5 a three-fold increase of surface emissivity from $\epsilon = 0.05$ to $\epsilon = 0.15$ results in a small increase in melt time. It is apparent that the insulation blanket thermal properties (conductivity and emissivity) have little effect on the melting of the insulation blanket.

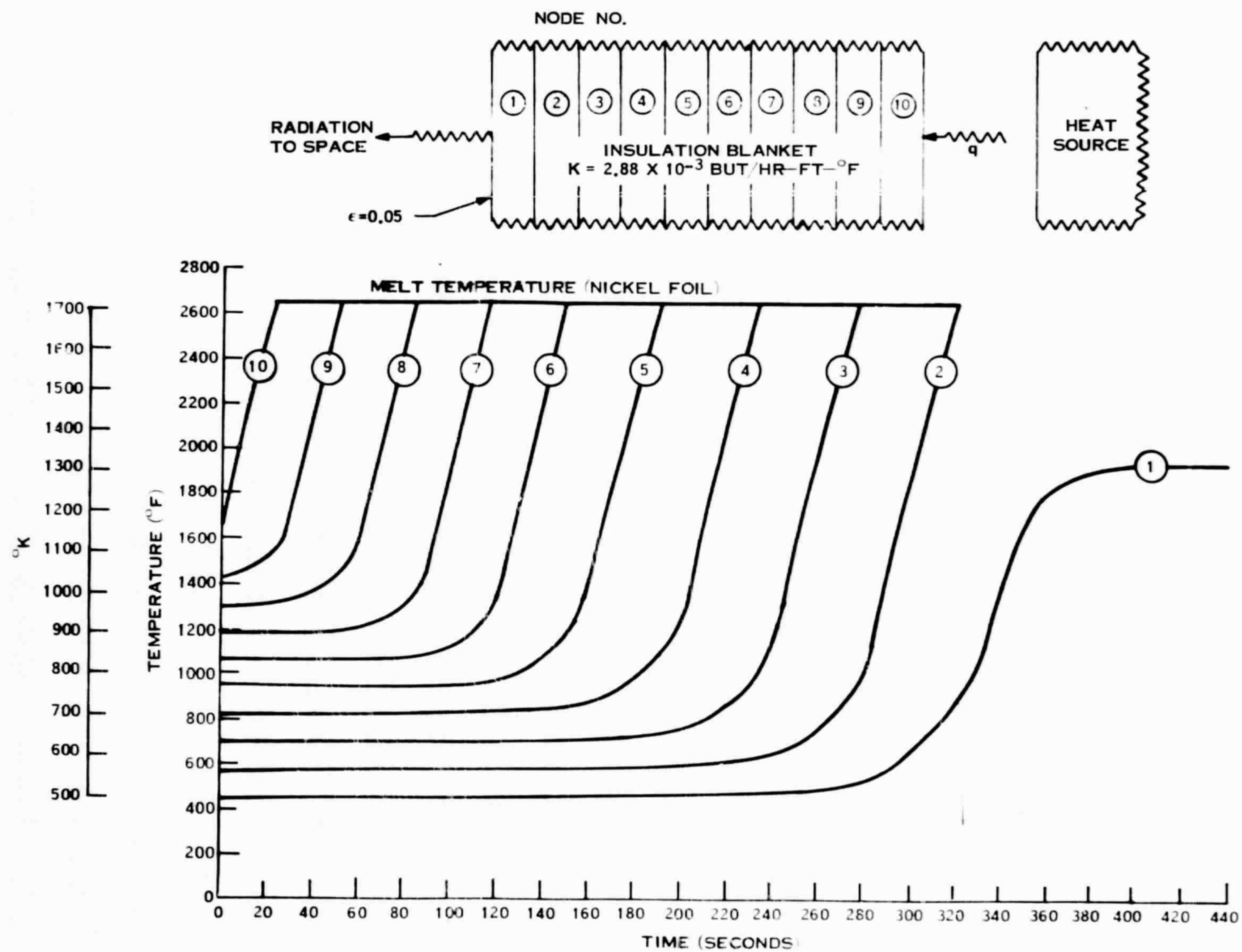


Figure 6-3. Transient Temperature Response of Melting Insulation Blanket

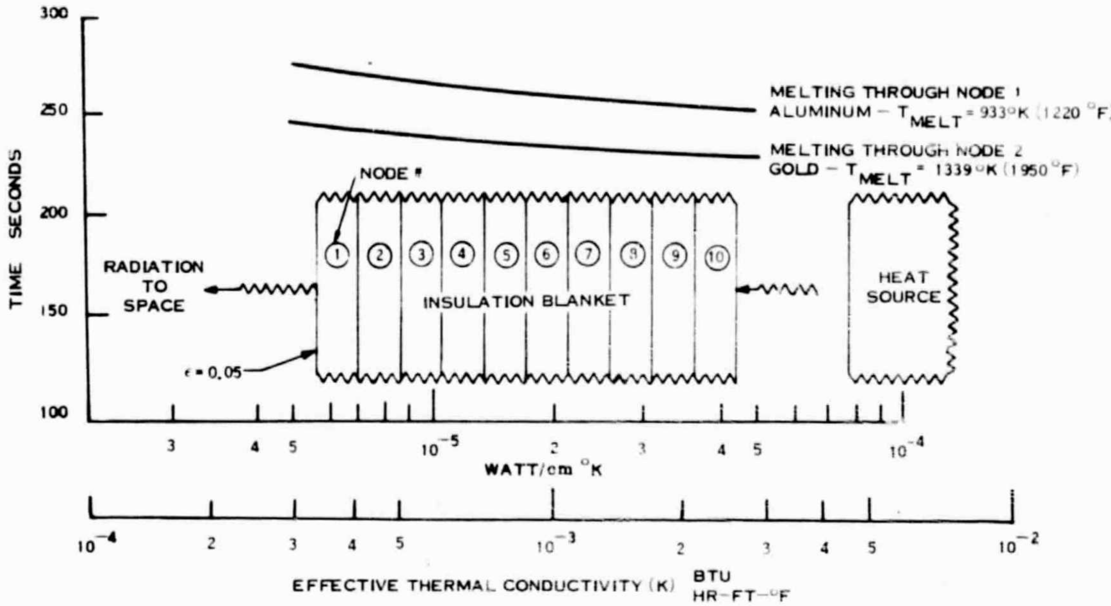


Figure 6-4. Effect of Thermal Conductivity on Insulation Blanket Melt Time

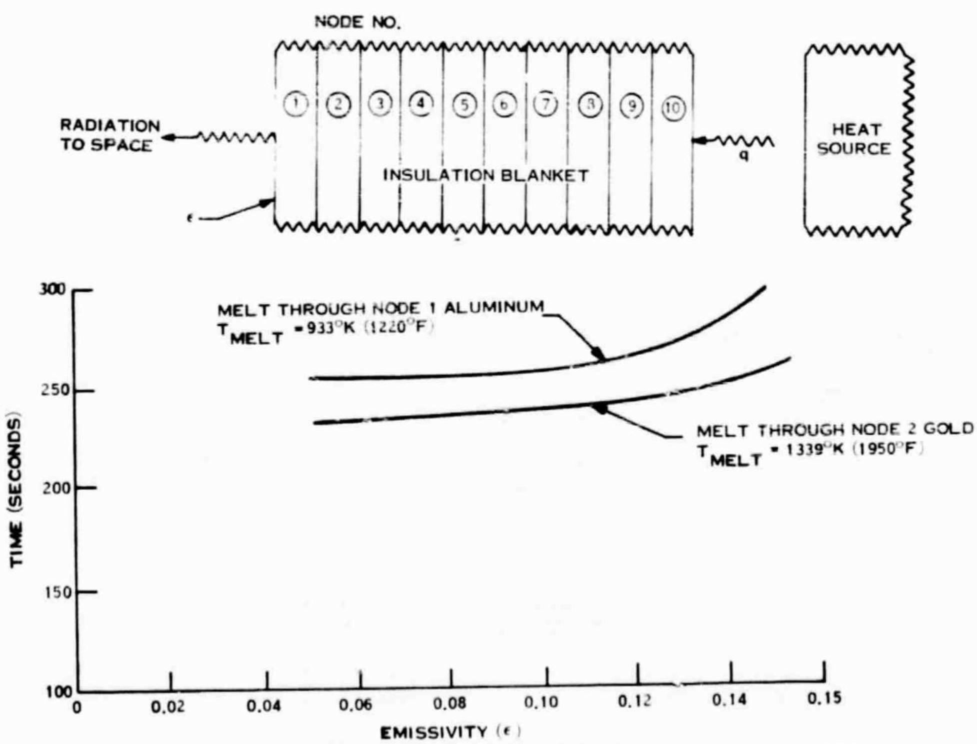


Figure 6-5. Effect of Emissivity on Insulation Blanket Melt Time

Figure 6-6 shows the effect of the product of the insulation blanket mass and specific heat parameter. Although the influence of this parameter on melt time is more pronounced than the other thermal parameters, the range of interest (from the value for gold (Au) to Nickel (Ni) shows an increase in melt time of the order of two minutes which is not considered to be significant.

This simplified study indicates that a melting insulation blanket emergency cooling device is feasible for the Mini-Brayton Heat Source. Some uncertainties about the phenomenon which do not lend themselves to analysis, however, remain to be resolved. Since the melting starts at the inside and progresses to the outer layers, what are the effects of the liquid and/or vapor that may be trapped?

It is also possible that localized melting might occur due to non-uniformities in the blanket, which may cause the formation of holes through the blanket and result in an equilibrium condition which causes the melting to stop. Hopefully, for this condition, the hole through the blanket would be sufficient to short-circuit the insulation sufficiently so that the heat source could radiate the generated energy at a safe temperature level.

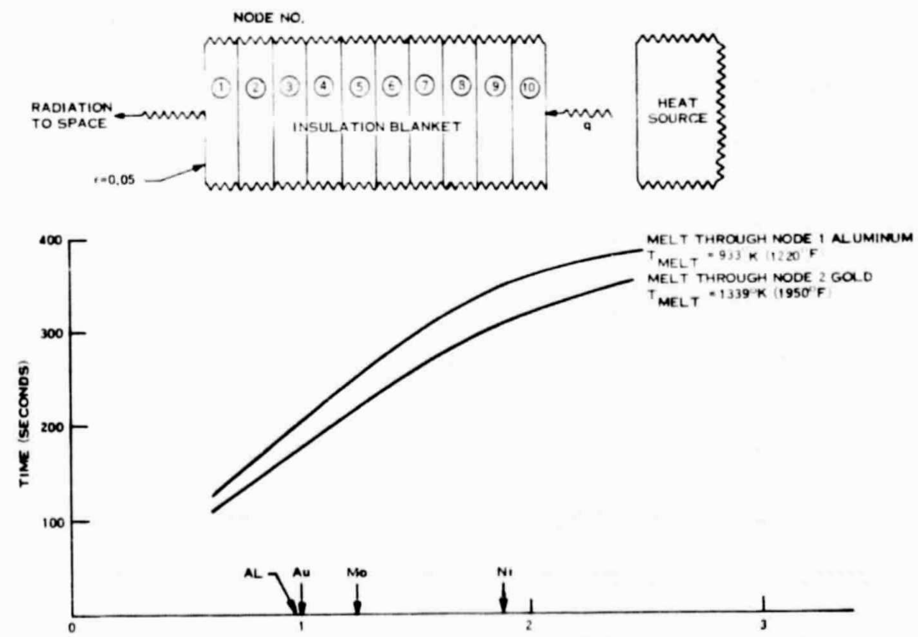


Figure 6-6. Effect of Mass X Specific Heat on Insulation Blanket Melt Time

A test program would be required to establish the validity of the melting insulation for emergency cooling. It is concluded at the present time that the melting insulation concept should be considered the prime candidate for this function.

Back-up alternate emergency cooling can be effected by mechanically removing insulation panels by utilizing hinged doors (similar to the Space Shuttle mission design in Volume I) or by ejecting the panels. Activation can be accomplished by fusible (melting) mechanical links, gas expansion devices or pyrotechnic devices.

6.2 AUXILIARY COOLING SUBSYSTEM

6.2.1 REQUIREMENTS

Duirng pad operations HSA auxiliary cooling must be accomplished to preclude oxidation of the Heat Source graphite emissivity sleeve and the HSHX refractory alloy. This can be done by either lowering the temperatures of these components below the oxidizing limits ($\sim 500^{\circ}K$) or by providing an inert gas environment. The approach used in the reference design is to impose an inert atmosphere around the HSA which prevents oxidation. As an additional benefit the inert gas thermally short circuits the multifoil insulation and lowers the temperature of the heat source substantially below its operational temperature. Inert gas from a ground supply is transferred into the HSA by means of a quick-disconnect fitting attached to the outer insulation clad. As such, there are no auxiliary cooling port penetrations through the insulation blanket which would cause an operational heat leak from the HSA in space. The gas flows slowly through the insulation system, and into the cavities between HSHX and insulation and the HSHX and the Heat Source. Oxygen is prevented from getting into the system by maintaining a positive inert gas pressure within the HSA. Helium or argon are candidates for the inert gas. Prior to power start-up, the inert gas must be removed from the HSA to permit the attainment of operational temperatures. In the present concept the inert gas inlet tube is disconnected immediately prior to launch. The rate at which the HSA heats up is a function of how rapidly the gas is removed from the system. Assuming immediate expulsion of the gas, a minimum of 100 minutes are available before start-up need be effected.

Operational flexibility can be achieved by sealing the HSA at the launch site and providing a pressure relief device for venting the entrapped helium in orbit. In this manner unplanned "holds" on the launch pad after cooling disconnect, and delays in starting up the Mini-Brayton power system in orbit can be readily accommodated.

An alternate auxiliary cooling scheme is to provide a forced cooling flow directly over the heat source as proposed in Volume I for the Space Shuttle Mission. The major disadvantage of this approach is the operational heat leak due to penetration through the insulation blanket. Table 6-1 gives a trade-off comparison between the two approaches. It is considered that further test evaluation is required to make a final selection of the system.

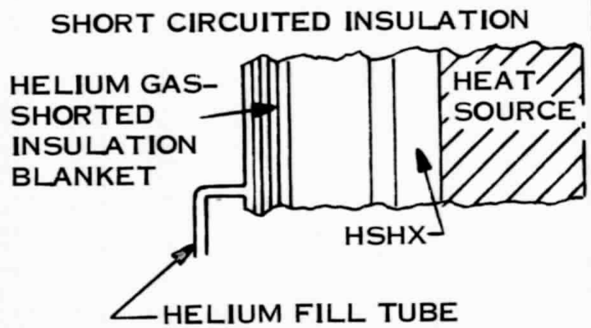
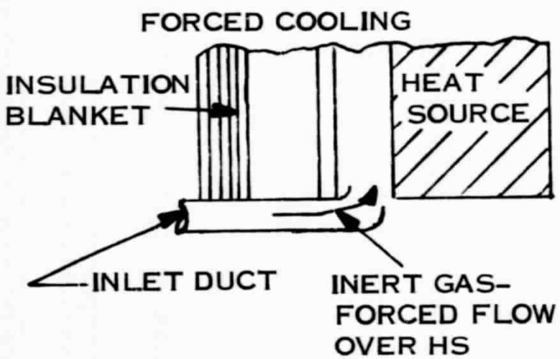
6.3 INSULATION BLANKET

A nickel multifoil insulation blanket is used as the reference design. This multifoil insulation concept consists of many layers of thin metal foils separated from one another by high purity refractory oxide particles such as zirconia. The layers of metal foil, which typically are a quarter of a mil to one mil thick, act as thermal radiation barriers. The oxide particles prevent adjacent foils from coming in contact with one another forming a metal-to-metal conduction path. The oxide particles are a few microns in diameter and are sprayed onto one side of each foil. The particle coatings are relatively sparse, and the low thermal conductivities of the oxides plus the high contact resistance between particles and foil minimize the conduction component of the total heat transfer through the insulation.

A sixty layer blanket will limit the heat loss through the insulation during orbit operation to approximately 5% (excluding end blanket penetration losses). The insulation stack-up is typically about 4 mils/layer (for 1/2 mil foils), so the 60 foil reference system would be approximately 0.64 cm (0.24 inches); the density is approximately 7.3 kg/m^2 (1.5 lb/ft^2).

An alternate candidate insulation system consists of metal foils separated by glass fiber insulating layers. A sixty layer foil system was configured for minimum weight consisting of 21 layers of gold foil, 28 layers of copper foil and 11 layers of aluminum foil. The gold foils are inboard (closest to the HSHX) and the aluminum foil outboard. Although copper is

Table 6-1. Comparisons of Auxiliary Cooling On Pad

	PROS	CONS
	• SIMPLE • NEGLIBLE OPERATIONAL HEAT LOSS PENALTY • MAY ALLOW UNATTENDED GROUND OPERATIONS WITH LOADED HEAT SOURCE	• MAY REQUIRE PRESSURE RELIEF DEVICE TO VENT INSULATION • RESULTANT TEMPERATURE OF HSHX AND HS SAFE BUT HIGHER THAN FORCED COOLING • REQUIRES EXTERNAL COOLING TO LIMIT HSA EXTERNAL SURFACES TO 380°F
	• POSITIVE CONTROL WITH FLOW DIRECTLY OVER HS • LOWER REFRACTORY HSHX AND HEAT SOURCE TEMPERATURE THAN SHORT CIRCUITED INSULATION $\Delta T > 400°F$	• OPERATIONAL HEAT LEAK $\sim$ 0.5% (12 WATTS) • REQUIRES EXTERNAL COOLING TO LIMIT EXTERNAL HSA SURFACES TO 380°F • LOSS OF COOLING CAN RESULT IN HEAT SOURCE OVER-TEMPERATURE

considerably lighter than gold, its high vapor pressure at elevated temperatures preclude its use at greater than $1053^{\circ}K$ ($1436^{\circ}F$), corresponding to a vapor pressure of 10^{-7} torr. Consequently it cannot be used inboard where the temperatures exceed this limit. The stack up for this blanket of of 1/2 mil foil and 5 mil glass separators is typically 1 to 1.8 cm (0.4 to 0.7 in.) with an areal density of approximately 10.7 Kg/m^2 (2.2 lb/ft^2).

The high bulk density nickel foil system was judged to be more attractive for the HSA application due to the lighter weight afforded by this design. A second advantage of this type of insulation system is that it is 1/2 to 1/3 the thickness of the two layer foil/separator system. This feature allows the inert gas to more effectively thermal short circuit the insulation during the on-pad cooling operation, thus providing lower on-pad HSA temperatures.

SECTION 7

CONCLUSIONS AND RECOMMENDATIONS

SECTION 7

CONCLUSIONS AND RECOMMENDATIONS

The objective of designing a Heat Source Assembly that weighs less than 40 kg (88 lb) and that meets nuclear safety criteria for a Titan IIIC mission has been accomplished. The selected Reference Baseline HSA design utilizes a refractory alloy machined plate fin Heat Source Heat Exchanger fabricated from either Cb-103 or Cb-1Zr. Maximum use is made of Heat Source support hardware developed and built for the Multi-Hundred Watt-RTG system. Weight reductions relative to the HSA design for a Space Shuttle mission (discussed in Volume I) have been effected by:

1. Eliminating end doors
2. Optimizing HSHX and header wall gauges
3. Simplifying HSHX support structure and
4. Reducing the overall HSA envelope.

Melting insulation is recommended for emergency cooling in event of a Mini-Brayton system failure.

There is a high level of confidence that the HSA as defined in this study can be fabricated and integrated into a Mini-Brayton system that will operate reliably in space for 5 to 10 years. There are, however, three areas of technology development that must be pursued.

1. Test demonstration of the melting insulation emergency cooling concept
2. Additional material characterization of the two candidate HSHX refractory alloys Cb-103 and Cbl-Zr
3. Fabrication development, e.g., diffusion bonding of the HSHX.

These technology developments are consistent with an evolving program whose mission requirements are not definitized and that may even prescribe development of a new generation rectangular geometry curium heat source. The HSA design is modular and the subsystems concepts (HSHX, emergency cooling insulation blanket, auxiliary cooling) sufficiently flexible to be essentially insensitive to heat source geometry or fuel selection. The technology development should therefore be pursued. Technology development can be completed along with fabrication and assembly of engineering prototype HSA hardware for Mini-Brayton system demonstration and life tests, within an eighteen (18) to twenty-four (24) month time frame.

APPENDIX A

ACRONYMS

APPENDIX A

ACRONYMNS

ACS	Auxiliary Cooling Subsystem
BRU	Brayton Rotating Unit (Turbine - Alternator - Compressor Assembly)
EB	Electron Beam (Welding)
ECD	Emergency Cooling Device (A device which automatically releases the emergency cooling doors)
ECS	Emergency Cooling Subsystem (The combination of ECD and Emergency Cooling Doors for the Space Shuttle mission or melting insulation for the Titan IIIC mission)
FFBD	Functional Flow Block Diagram
GSE	Ground Support Equipment
GTA	Gas Tungsten Arc (Welding)
HS	Heat Source
HSA	Heat Source Assembly
IGS	Inert Gas Subsystem (Identical to the ACS with the use of a pure inert gas and appropriate valving as required).